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Fugitive Emission Sources of Organic Compounds Additional Information on Emissions, Emission Reductions, and Costs

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16. ABSTRACT

Standards of performance to control fugitive emissions of VOC from new, modified, and reconstructed Synthetic Organic Chemical Manufacturing Industry (SOCMI) process units were proposed on January 5, 1981 (46 FR 1136). This document contains the data and methodologies which EPA believes most accurately characterizes SOCMI fugitive emission rates of VOC, effectiveness of control techniques, and control costs.

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Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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1. INTRODUCTION AND SUMMARY

1.1 PURPOSE

A number of equipment components used in chemical manufacturing processes in the Synthetic Organic Chemical Manufacturing Industry (SOCMI) are sources of fugitive emissions. These fugitive emission sources (pumps, valves, flanges, compressors, sampling systems, open-ended lines, and pressure relief valves) have a common feature -- a point of interface of the process fluid with the atmosphere. These points of interface such as seals, packings, and gaskets have a tendency to fail mechanically and thereby leak process fluid. These leaks (if the process fluid is a volatile organic compound) cause emissions of volatile organic compounds (VOC) to the atmosphere. The nature of these emission sources is that leaks can occur at any time and the majority of the emissions come from a few sources of different types. These leaks can be reduced by using equipment which prevents or reduces leakage, such as sealless pumps, or by detecting leaks and repairing them.

Standards of performance for fugitive emission sources of VOC in the Synthetic Organic Chemical Manufacturing Industry (SOCMI) were proposed on January 5, 1981 (46 FR 1136). The proposed standards were supported by technical information and analysis in the Background Information Document (BID) (EPA-450/3-80-033a). The BID contains estimates of uncontrolled and controlled fugitive emissions of VOC and costs for the emission reduction techniques.

Since the BID was published, several relevant reports concerning fugitive emissions have been completed. A Federal Register notice was published on April 14, 1981 (46 FR 21789) to announce the availability of and inviting comments on these reports. The Office of Air, Noise and Radiation of the U.S. Environmental Protection Agency (EPA) reviewed the new information in these reports and the comments received on the new information. Based upon a review of all information now available and in the comments, EPA has reached conclusions on the data and methodology which EPA believes to characterize SOCMI fugitive rates, effectiveness of control techniques, and control costs.

These conclusions are being made available in this document as a basis for public comment. Comments on this document will be used in making decisions concerning fugitive emission sources. Even though much of the technical information and methodologies are the same as those presented in the BID, some changes and some additions have been made to the technical information and methodologies. In some cases EPA has concluded that certain data are inappropriate for use in decision making. Because these conclusions are fundamental to decision making concerning fugitive emission sources, they are being presented in advance for review before the final decisions are made.

The information in this document is restricted to selection of technical information, data, and calculation methods. It is not a general discussion of fugitive emission sources and emission reduction techniques as presented in the BID. This document contains specific technical details applicable to some aspects of the more generalized BID discussions. Comments are requested on these selections as they are presented in the four major sections in the remainder of this document:

Emission Factors (Section 2)
Model Units (Section 3)
Emission Reductions (Section 4)
Costs (Section 5)

In each of these sections the technical basis presented in the BID is briefly reviewed. Also, each section presents information developed since the publication of the BID and relevant public comments received by EPA. Each section concludes with EPA's conclusions and related rationale.

1.2 HIGHLIGHTS OF CONCLUSIONS

Although several minor changes to the analysis presented in the BID are being considered by EPA, two important changes concern the emission factors and the methodology used for calculating the effectiveness of a leak detection and repair program. Both of these changes would result from taking full advantage of the latest information and data.

The SOCMI emission factors presented in the BID were derived from petroleum refineries. For reasons only partially understandable, the SOCMI fugitive emissions data showed a difference in the number of leaking and non-leaking sources (leak frequency) when compared to the data derived from petroleum refineries. Even though the SOCMI plants tested were not necessarily representative of SOCMI as a whole, an average leak frequency from these SOCMI plants may better approximate SOCMI fugitive emissions than the average leak frequency from petroleum refining plants. Therefore, the SOCMI emission factors have been adjusted to more accurately reflect the number of leaking and non-leaking sources found in the process units tested. The adjustment was made by dividing the petroleum refinery emission factors into leaking and non-leaking[a] factors. These two factors were then applied according to the number of leaking and non-leaking sources found in SOCMI.

Two of the emission factors were developed in slightly different ways. The sampling connection emission factor is the same for SOCMI and petroleum refineries. The factor is a quantitative estimate of the amount of emissions due to purging the sample lines and will be the same in both types of process units. The gas valve emission factor was developed using the approach of applying leaking and non-leaking emission factors to SOCMI leak frequencies. However, SOCMI gas valve leaking and non-leaking emission factors were used instead of petroleum refinery leaking and non-leaking emission factors.

The method presented in the BID (Chapter 4) for calculating the effectiveness of leak detection and repair programs was the ABCD model. The ABCD model adjusts the theoretical maximum control efficiency (A) for occurrence and recurrence of leaks (B), time to repair (C), and repair to less than 10,000 ppm but not to zero emissions (D). The model, although easy to use, has some disadvantages and does not fully represent phenomena observed for fugitive emissions. With new information available, EPA can use a Leak Detection and Repair (LDAR) model which better represents observed fugitive emission behavior. The LDAR model, developed in September, 1981, also is more flexible in allowing calculations for different types of leak detection and repair programs.

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[a] "Leaking" means screening at or above 10,000 ppm with a portable VOC monitor. "Non-leaking" means screening below 10,000 ppm. "Non-leaking" does not mean that no emissions occur.

1.3 SUMMARY OF RESULTS

The major results of EPA's review of the technical basis presented in the BID, new information which has become available, and public comments are summarized here. Details and reasoning supporting the results may be found in the corresponding sections.

1.3.1 Emission Factors (Section 2)

The emission factors which EPA plans to use in estimating fugitive emissions of VOC from SOCMI are shown in Table 1-1. They were developed by using (1) SOCMI leak frequencies (i.e., number of leaking and non-leaking fugitive emission sources) and (2) emission factors determined in petroleum refineries and SOCMI units for leaking and non-leaking fugitive emission sources. The resulting emission factors are lower than the emission factors presented in the BID for all equipment components except flanges and sampling connections.

TABLE 1-1. EMISSION FACTORS FOR AVERAGE SOCMI UNIT, kg/hr/source

Source	Average SOCMI Emission Factor (kg/hr/source)
Pumps - light liquid	0.0494
- heavy liquid	0.0214
Valves - gas	0.0056
- light liquid	0.0071
- heavy liquid	0.00023
Compressors	0.228
Safety/relief valves - gas	0.104
Flanges	0.00083
Open-ended lines	0.0017
Sampling connections	0.0150

1.3.2 Model Units (Section 3)

The model units which will be used by EPA to estimate fugitive emissions of VOC in a process unit are shown in Table 1-2. The equipment counts remain the same as those in the BID analysis. The valves associated with open-ended lines have been incorporated in the valve counts leaving only emissions from the open-end in the "open-ended lines" category.

1.3.3 Emission Reductions (Section 4)

EPA has concluded that the effectiveness of leak detection and repair programs for valves and pumps is most accurately calculated by using the LDAR model. The conclusions on the effectiveness of leak detection and repair programs for valves and pumps have been used to modify the ABCD estimates presented in the BID. The results obtained with the LDAR are presented in Table 1-3. EPA's estimate of efficiency for the use of open-ended lines with plugs or caps, closed purge sampling systems and dual seals with barrier fluids and vent systems and rupture disks on safety relief valves remain unchanged and are about 100 percent. Enclosed combustion devices can be expected to achieve 98 percent reduction in VOC. Most other types of control devices (new and existing) can achieve a reduction of 95 percent. Furthermore, a 90 percent control efficiency to flares will be assumed for purposes of estimation.

TABLE 1-2. EQUIPMENT COUNTS FOR FUGITIVE VOC EMISSION SOURCES IN SOCMI MODEL UNITS

	Equipment Counts[b]					
	BID Analysis			Revised Analysis		
Equipment Component[a]	Model Unit A	Model Unit B	Model Unit C	Model Unit A	Model Unit B	Model Unit C
Pump Seals						
Light Liquid Service						
Single mechanical	5	19	60	5	19	60
Dual mechanical	3	10	31	3	10	31
Sealless	0	1	1	0	1	1
Heavy Liquid Service						
Single mechanical	5	24	73	5	24	73
Packed	2	6	20	2	6	20
Valves						
Vapor service	90	365	1117	99	402	1232
Light liquid service	84	335	1037	131	524	1618
Heavy liquid service	84	335	1037	132	524	1618
Safety/relief valves						
Vapor service	11	42	130	11[c]	42[c]	130[c]
Light liquid service	1	4	13	1	4	13
Heavy liquid service	1	4	14	1	4	14
Open-ended lines				104[d]	415[d]	1277[d]
Vapor service	9	37	115			
Light liquid service	47	189	581			
Heavy liquid service	48	189	581			
Compressor seals	1	2	8	1	2	8
Sampling connections	26	104	320	26[e]	104[e]	320[e]
Flanges	600	2400	7400	600	2400	7400

[a] Equipment components in VOC service only.

[b] 52% of existing units are similar to Model Unit A.
33% of existing units are similar to Model Unit B.
15% of existing units are similar to Model Unit C.

[c] Seventy-five percent of gas safety/relief valves are assumed to be controlled at baseline; therefore the emissions estimates are based on the following counts: A,3; B,11; C,33.

[d] All open-ended lines are considered together with a single emission factor; 100% controlled at baseline.

[e] Seventy-five percent of sampling connections are assumed to be controlled at baseline, therefore, the emissions estimates are based on the following counts: A,7; B,26; C,80.

TABLE 1-3. ESTIMATED CONTROL EFFECTIVENESS FOR LEAK DETECTION AND REPAIR PROGRAMS FOR VALVES AND PUMPS (decimal percent)

Monitoring Interval	Valves		Pumps
	Gas	Light Liquid	
Monthly	0.73	0.59	0.608
Monthly/Quarterly	0.65	0.46	-
Quarterly	0.64	0.44	0.325
Semiannual	0.50	0.22	(0.076)[a]
Annual	0.24	(0.19)	(0.800)[a]

[a] Values in parentheses indicate negative efficiencies.

1.3.4 Cost Estimates (Section 5)

EPA's estimate for the cost to reduce fugitive emissions are presented in Section 5. The cost basis is similar to the basis presented in the BID.

2. EMISSION FACTORS

Estimates of emissions from fugitive emission sources in a process unit are made by applying fugitive emission factors for each source (pumps, valves, compressors, etc.) to the number of sources in a process unit or plant. (Model Units are discussed in Section 3). This section contains a review of the data which were available when the BID (EPA-450/3-80-033a)[1], was published, and an explanation of the basis for the emission factors in the BID. New information which has been made available since proposal is presented and pertinent comments received from the public are summarized. Finally, this section presents EPA's conclusions concerning the new information and the numerical values which should be assigned to emission factors in SOCMI.

2.1 TECHNICAL BASIS PRESENTED IN THE BID

Information available at the time of proposal concerning VOC emissions from fugitive emission sources was presented in the Background Information Document. The information consisted of the results of several studies of fugitive emissions. Descriptions of the studies and their results were presented in Appendix C.

2.1.1 Petroleum Refinery Study[2]

Data concerning the VOC emitter frequencies (an emitter was defined as a source screening at or above 200 ppmv) and emission factors for various fugitive sources were obtained primarily at nine refineries. More complete information for compressor and relief valve emissions was obtained by sampling at four additional refineries. Refineries were selected to provide a range of sizes and ages and all of the major petroleum refinery processing units were studied. The type of process units and the number of each studied in the first nine refineries are listed in Table 2-1.

In each refinery, sources in six to nine process units were selected for study. The approximate number of sources selected for study and testing in each refinery is listed below:

TABLE 2-1. SAMPLED PROCESS UNITS FROM NINE REFINERIES DURING REFINERY STUDY

Refinery process unit	Number of sampled units
Atmospheric distillation	7
Vacuum distillation	4
Thermal operations (coking)	2
Catalytic cracking	5
Catalytic reforming	6
Catalytic hydrocracking	2
Catalytic hydrorefining	2
Catalytic hydrotreating	7
Alkylation	6
Aromatics/isomerization	3
Lube oil manufacture	2
Asphalt manufacture	1
Fuel gas/light-ends processing	11
LPG	2
Sulfur recovery	1
Other	3

Valves	250-300
Flanges	100-750
Pump seals	100-125
Compressor seals	10-20
Drains	20-40
Relief Valves	20-40

There were normally 500-600 sources selected in each refinery.

The distribution of sources among the process units was determined before the selection and testing of individual sources was begun. Individual sources were selected from piping and instrumentation diagrams or process flow diagrams before a refinery processing area was entered. Only those preselected sources were screened. In this way, potential bias which could have resulted from observation of individual sources was eliminated.

The screening of sources was accomplished with portable organic vapor detectors. The principal device used in this study was the J.W. Bacharach Instrument Co.* "TLV Sniffer" calibrated with hexane. The components were tested on an individual basis and only those components with measured VOC concentrations in excess of 200 ppmv (i.e. emitters) were considered for further study. Leak frequencies based on 10,000 ppmv (TLV-hexane) could be determined from the reported results as well.

Emitter frequencies were evaluated for each process type. In a later analysis of the source data, leak frequencies were reported by source and service for each process type. These leak frequencies are shown in Tables 2-2 through 2-6.

A substantial number of sources were enclosed and both the methane and nonmethane emission rates from the sources were determined. An important result of this program was the development of emission factors and the quantification of the relationship between the maximum observed screening value (VOC concentration) and the measured nonmethane leak rate. Emission factors, emitter frequency, and leak frequency information generated during this study are given in Table 2-7. The values reported in the BID were from an interim report (EPA-600/2-79-044).[3] The values in Table 2-7 are slightly different since they came from the final report (EPA-600/2-80-075c).[4]

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*Mention of a company name does not represent endorsement by EPA.

TABLE 2-2. LEAK FREQUENCY IN REFINERIES BY PROCESS UNIT - VALVES[a]

Unit Code	Unit Identification	GAS SERVICE Number Screened	GAS SERVICE Percent Leaking	GAS SERVICE 95% Conf. Interval	LIGHT LIQUID SERVICE Number Screened	LIGHT LIQUID SERVICE Percent Leaking	LIGHT LIQUID SERVICE 95% Conf. Interval	HEAVY LIQUID SERVICE Number Screened	HEAVY LIQUID SERVICE Percent Leaking	HEAVY LIQUID SERVICE 95% C.I.
15	Atmospheric Distillation	69	8.7	(3,18)	63	9.5	(4,20)	143	0	(0,3)
13	Fuel Gas/Light Ends Processing	185	12.4	(8,18)	246	17.1	(12,23)	27	0	(0,13)
22	Catalytic Cracking	50	16.0	(7,29)	59	10.2	(4,21)	80	0	(0,5)
1	Catalytic Reforming	22	27.3	(11,50)	85	10.6	(5,19)	0	-	-
27	Alkylation	59	23.7	(14,37)	151	19.2	(13,27)	4	0	(0,60)
17	Vacuum Distillation	13	0	(0,25)	2	0	(0,84)	42	0	(0,8)
2,4,8	Catalytic Hydrotreating/ Refining	63	6.3	(2,15)	116	4.3	(1,10)	57	1.8	(0,9)
33	Aromatics Extraction	18	5.6	(1,35)	24	4.2	(0,21)	2	0	(0,84)
23	Delayed Coking	27	0	(0,13)	29	6.9	(0,23)	30	0	(0,12)
32,34 35	Dewaxing, Treating	37	16.2	(6,32)	159	6.9	(3,12)	93	0	(0,4)
18	Sulfur Recovery	7	0	(0,41)	0	-	-	3	0	(0,71)
5	Hydrocracking	6	16.6	(0,64)	32	9.4	(2,25)	15	0	(0,22)
11	Hydrogen Production	8	12.5	(0,53)	4	0	(0,60)	15	0	(0,22)
36	Hydrodealkylation	6	16.1	(0,64)	24	0	(0,14)	0	-	-
	Other	0	-	-	1	0	(0,100)	11	0	(0,28)

[a] Source: Reference 5.

Note: A leak is defined as a TLV screening value $\geq$10,000 ppmv, calibrated with hexane.

TABLE 2-3. LEAK FREQUENCY IN REFINERIES BY PROCESS UNIT - COMPRESSOR SEALS[a]

Unit Code	Unit Identification	HYDROCARBON GAS SERVICE Number Screened	Percent Leaking	95% Conf. Interval	HYDROGEN GAS SERVICE Number Screened	Percent Leaking	95% Conf. Interval
15	Atmospheric Distillation	6	66.7	(22,96)	0	-	-
13	Fuel Gas/Light Ends Processing	62	37.1	(25,50)	0	-	-
22	Catalytic Cracking	37	54.1	(37,71)	0	-	-
1	Catalytic Reforming	1	0	(0,100)	41	41.5	(26,58)
27	Alkylation	10	70.0	(35,93)	0	-	-
17	Vacuum Distillation	0	-	-	0	-	-
2,4,8	Catalytic Hydrotreating/ Refining	0	-	-	26	50.0	(30,70)
33	Aromatics Extraction	1	100	(0,100)	2	100	(16,100)
23	Delayed Coking	14	100	(77,100)	0	-	-
32,34 35	Dewaxing, Treating	12	25.0	(5,57)	1	100	(0,100)
18	Sulfur Recovery	0	-	-	0	-	-
5	Hydrocracking	0	-	-	9	0	(0,34)
11	Hydrogen Production	0	-	-	0	-	-
36	Hydrodealkylation	0	-	-	2	0	(0,84)
	Other	0	-	-	2	0	(0,84)

Source: Reference 6.
Note: A leak is defined as a TLV screening value $\geq$10,000 ppmv, calibrated with hexane.

TABLE 2-4. LEAK FREQUENCY IN REFINERIES BY PROCESS UNIT[a]
- RELIEF VALVES -

Unit Code	Unit Identification	GAS SERVICE Number Screened	GAS SERVICE Percent Leaking	GAS SERVICE 95% Conf. Interval
15	Atmospheric Distillation	16	0	(0,21)
13	Fuel Gas/Light Ends Processing	57	3.5	(0,12)
22	Catalytic Cracking	19	5.3	(0,26)
1	Catalytic Reforming	12	8.3	(0,38)
27	Alkylation	29	13.8	(4,32)
17	Vacuum Distillation	1	0	(0,100)
2,4,8	Catalytic Hydrotreating/ Refining	12	16.7	(2,48)
33	Aromatics Extraction	4	0	(0,60)
23	Delayed Coking	3	0	(0,71)
32,34 35	Dewaxing, Treating	10	0	(0,31)
18	Sulfur Recovery	0	-	-
5	Hydrocracking	4	0	(0,60)
11	Hydrogen Production	2	0	(0,84)
36	Hydrodealkylation	0	-	-
	Other	0	-	-

[a] Source: Reference 7.

Note: A leak is defined as a TLV screening value $\geq$10,000 ppmv, calibrated with hexane.

TABLE 2-5 . LEAK FREQUENCY IN REFINERIES BY PROCESS UNIT - PUMP SEALS[a]

Unit Code	Unit Identification	LIGHT LIQUID SERVICE Number Screened	Percent Leaking	95% Conf. Interval	HEAVY LIQUID SERVICE Number Screened	Percent Leaking	95% Conf. Interval
15	Atmospheric Distillation	51	19.6	(10,33)	94	9.6	(4,17)
13	Fuel Gas/Light Ends Processing	127	25.2	(18,34)	26	3.8	(0,20)
22	Catalytic Cracking	34	26.5	(13,44)	43	0	(0,8)
1	Catalytic Reforming	33	30.3	(16,49)	0	-	-
27	Alkylation	70	41.4	(30,54)	0	-	-
17	Vacuum Distillation	0	-	-	25	0	(0,14)
2,4,8	Catalytic Hydrotreating/ Refining	40	7.5	(2,20)	20	0	(0,17)
33	Aromatics Extraction	38	15.8	(6,31)	3	0	(0,71)
23	Delayed Coking	18	11.1	(1,35)	19	0	(0,18)
32,34 35	Dewaxing, Treating	32	21.9	(9,40)	33	3.0	(0,16)
18	Sulfur Recovery	0	-	-	0	-	-
5	Hydrocracking	22	13.6	(3,35)	18	0	(0,19)
11	Hydrogen Production	0	-	-	6	0	(0,46)
36	Hydrodealkylation	5	40.0	(5,85)	0	-	-
	Other	0	-	-	5	0	(0,52)

[a] Source: Reference 6.

Note: leak is defined as a TLV screening value ≥10,000 ppmv, calibrated with hexane.

TABLE 2-6. LEAK FREQUENCY IN REFINERIES BY PROCESS UNIT[a]
- FLANGES -

Unit Code	Unit Identification	ALL SERVICES Number Screened	ALL SERVICES Percent Leaking	ALL SERVICES 95% Conf. Interval
15	Atmospheric Distillation	411	0	(0,1)
13	Fuel Gas/Light Ends Processing	148	1.4	(0,5)
22	Catalytic Cracking	252	0	(0,1)
1	Catalytic Reforming	263	2.3	(1,5)
27	Alkylation	269	0.4	(0,2)
17	Vacuum Distillation	78	0	(0,5)
2,4,8	Catalytic Hydrotreating/ Refining	351	0.9	(0,3)
33	Aromatics Extraction	15	0	(0,22)
23	Delayed Coking	32	0	(0,11)
32,34 35	Dewaxing, Treating	300	0.3	(0,2)
18	Sulfur Recovery	6	0	(0,46)
5	Hydrocracking	33	3.0	(0,16)
11	Hydrogen Production	19	0	(0,18)
36	Hydrodealkylation	15	0	(0,22)
	Other	3	0	(0,71)

[a] Source: Reference 9.

Note: A leak is defined as a TLV screening value ≥10,000 ppmv, calibrated with hexane.

TABLE 2-7. PERCENT OF SOURCES LEAKING AND EMISSION FACTORS FOR FUGITIVE EMISSION SOURCES IN PETROLEUM REFINERIES (95 Percent Confidence Intervals)[a]

Equipment Type	Percent of Sources Screening ≥200 ppmv TLV-hexane	Percent of Sources Screening >10,000 ppmv TLV-hexane	Average Emission Factor[b] kg/hr/source
Valves			
Gas	30 (25, 36)	10 (6.5, 14)	0.0268 (0.014, 0.050)
Light Liquid	37 (33, 43)	11 (7.5, 14)	0.0109 (0.008, 0.016)
Heavy Liquid	9 (4.2, 14)	0.2 (0, 1)	0.00023(0.00009,0.021)
Pump seals			
Light Liquid	66 (62, 70)	24 (20, 26)	0.114 (0.073, 0.17)
Heavy Liquid	28 (21, 35)	2 (0, 5.2)	0.021 (0.0086, 0.050)
Compressor Seals	79 (71, 88)	36 (25, 44)	0.636 (0.30, 1.32)
Pressure Relief Valves	32 (21, 42)	7 (1.8, 13)	0.086 (0.032, 0.22)
Gas			0.16
Light Liquid			0.006
Heavy Liquid			0.009
Flanges	5.7 (2.7, 8.6)	0.5[c]	0.00025(0.00009,0.0011)
Open-Ended Lines	22.4[c]	7.7[c]	0.0023 (0.0007, 0.007)

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[a] Source: Reference 10.

[b] Values presented in the above table are from the finalized Petroleum Refining Study (EPA-600/2-80-075c)[11] and may differ slightly from values presented in the BID which were based on an intermediate draft report (EPA-600/2-79-044).[12]

[c] No confidence intervals reported.

Another major conclusion drawn from the petroleum refinery study was the correlation between fugitive emission rates and process variables. The only equipment or process variable found to correlate with fugitive emission rates was the volatility and/or phase of the process stream. This result led to the separation of sources by service (gas/vapor, light liquid, heavy liquid) within equipment categories. Other variables such as line temperature and pressure indicated much lower degrees of correlation.

2.1.2 Four Unit EPA Study[13]

EPA-IERL (RTP), directed a study of fugitive emissions at four SOCMI units. This study was designed according to the same plan as was used for the Petroleum Refinery Study. Only four process units were surveyed, whereas the Refinery Study was based on sampling more than 64 different units. As seen in Table 2-8, this small number of units resulted in measured emitter frequencies and emission factor estimates with large confidence intervals for most source types. The process units tested were monochlorobenzene (MCB), butadiene (BUT), ethylene oxide/glycol (EOG), and dimethyl terephthalate (DMT).

Due to the small number of plants/processes sampled and the experimental design of this study, the results were not considered to be technically sound and therefore conclusions about emissions from SOCMI could not be drawn. Since valid conclusions could not be drawn concerning the magnitude of fugitive emissions in the SOCMI, the results of the study were not used in the development of standards for fugitive emissions control. This study demonstrated the need for more intensive sampling and screening which was undertaken by EPA.

2.1.3 EPA 6-Unit Study[14]

The objective of this test program was to gather data on the percentage of sources which leak (as defined by a VOC concentration at the leak interface of $\geq$10,000 ppmv calibrated with methane). To achieve this objective, an attempt was made to screen all potential leak sources (generally excluding flanges) on an individual component basis with a portable organic vapor analyzer. The test crews relied on plant personnel to identify equipment handling organics. Normally, all pumps and compressor seals were

TABLE 2-8. ORGANIC CHEMICAL INDUSTRY EMISSION FACTORS - Four Unit Study[a]

Source Type	Process	Total No.	Number Emitting[b]	Percent Emitting	95 Percent Conf. Interval	Emission Factor Estimate[c] kg/hr	95 Percent Confidence Interval for Estimate
Compressor	BUT	18	18	100.0	(81 - 100)	0.0564	(0.0222, 0.114)
Compressor	EOG	4	2	50.0	(6 - 93)	0.0043	(neg.[d], 0.764)
Flange	DMT	63	2	3.17	(0.39 - 11)	0.0068	(neg., >10)
Flange	EOG	91	12	13.2	(7.0 - 2)	0.00001	(neg., >10)
Flange	MCB	36	11	30.5	(16 - 48)	0.00108	(0.00011, 0.491)
Pump	BUT	23	13	56.5	(34 - 77)	0.0514	(0.0077, 0.271)
Pump	DMT	73	21	28.8	(19 - 41)	0.0029	(0.00046, 0.0152)
Pump	EGO	72	22	30.6	(20 - 43)	0.00886	(0.0013, 0.0550)
Pump	MCB	25	23	92.0	(74 - 99)	0.00266	(0.00014, 0.0342)
Sample Valve	DMT	14	9	64.3	(35 - 87)	0.0768	(0.0073, 0.555)
Valve	BUT	194	63	32.5	(25 - 39)	0.00306	(0.001, 0.00764)
Valve	DMT	63	4	6.3	(1.8 - 16)	0.00184	(0.00002, 0.582)
Valve	EOG	90	6	6.7	(3.9 - 17)	0.00002	(neg., >10)
Valve	MCB	37	9	24.3	(11 - 39)	0.00004	(neg., >10)

[a] Source: Reference 15.

[b] Emitting source is defined as an OVA-128 measurement >200 ppm equivalent methane or a leak rate >0.000005 kg/hr; the calibration standard used was the major component expected to be in the leak.

[c] Analysis of samples was by gas chromatography using a flame ionization detector, calibrated with standard gas mixtures made to correspond to the major constituents of the process lines tested.

[d] "Neg." indicates the value of confidence limit was less than 4.5×10^{-6} kg/hr.

[e] Upper confidence level is extremely large. The exact value has no physical meaning.

examined, and the percentage of valves in VOC service which were screened ranged from 33 to 85 percent. All tests were performed with a Century Systems Corporation Organic Vapor Analyzer, Model 108, with the probe placed as close to the source as possible. The results of this study are shown in Table 2-9.

Six chemical process units were screened. Unit A is a chlorinated methanes production facility in the Gulf Coast area which uses methanol as feedstock material. The individual component testing was conducted during September 1978. Unit B is a relatively small ethylene production facility on the West Coast which uses an ethane/propane feedstock. Testing was conducted during October 1978. Unit C is a chlorinated methanes production facility in the Midwest. This plant also uses methanol as the basic organic feedstock. During the years prior to screening, several pieces of equipment had been replaced with equipment the company felt was more reliable. In particular, the company installed certain types of valves which they found not to leak "as much" as other valves. The individual component testing was conducted during January 1979. Unit D is an ethylene production facility on the Gulf Coast, using an ethane/propane feed. The facility is associated with a major refinery, and testing was conducted during March 1979. Units E and F are part of an intermediate size integrated petroleum refinery located in the North Central United States. Testing was conducted during November 1978. Unit E is an aromatics extraction unit that produces benzene, toluene, and xylene by extraction from refined petroleum feedstocks. Unit E is a new unit and special attention was paid during the design and startup to minimize equipment leaks. All valves were repacked before startup (adding 2 to 3 times the original packing) and all pumps in benzene service had double mechanical seals with a barrier fluid. Unit F produces benzene by hydrodealkylation of toluene. Unit F was originally designed to produce a different chemical and was redesigned to produce benzene.

2.1.4 DuPont Study[16]

DuPont conducted a program of fugitive emission measurement from pumps and valves at two of their plants. The process types of the 5 and 10 year

TABLE 2-9. FREQUENCY OF LEAKS FROM FUGITIVE EMISSION SOURCES IN SYNTHETIC ORGANIC CHEMICAL UNITS (Six Unit Study)[a]

Equipment type	Unit A Chloromethanes Number of sources tested	Unit A Chloromethanes Percent with screening values ≥10,000 ppmv	Unit B Ethylene Number of sources tested	Unit B Ethylene Percent with screening values ≥10,000 ppmv	Unit C Chloromethanes Number of sources tested	Unit C Chloromethanes Percent with screening values ≥10,000 ppmv	Unit D Ethylene Number of sources tested	Unit D Ethylene Percent with screening values ≥10,000 ppmv	Unit E BTX Recovery Number of sources tested	Unit E BTX Recovery Percent with screening values ≥10,000 ppmv	Unit F Toluene HDA Number of sources tested	Unit F Toluene HDA Percent with screening values ≥10,000 ppmv
Valves	600	1	2301	19	658	0.1	862	14	715	1.1	427	7.0
Open-ended lines	52	2	386	11	[b]		90	13	33	0.0	28	11.0
Pump seals	47	15	51	21	39	3	63	33	33[c]	3.0	30	10.0
Compressor seals	[b]		42[d]	59	3	33	17	6	[b]		[b]	
Control valves	52	6	128	20	25	0	25	44	53	4.0	44	11.0
Pressure relief valves	7	0	[b]		[b]		[b]		[b]		[b]	
Flanges	30	3	[b]		[b]		[b]		[b]		[b]	
Drains	[b]		[b]		[b]		39	10	[b]		[b]	

[a] Source: Reference 17.

[b] No Data.

[c] Pump seals in benzene service have double mechanical seals.

[d] Compressors tested in this unit were reciprocating compressors found in the LD polyethylene production area.

Note: Screening conducted with an OVA-108 calibrated with methane.

old plants were not revealed. The OVA-108 was used for screening (leak identification) and for leak rate determination (analysis of collected leak vapors). The leak rate was determined by taking Tedlar bags partially filled with air and enclosing the leaking valve. The hydrocarbon concentration in the bags was recorded as a function of time. Leak rates were determined for a total of 6-8 valves. Visual estimates of the initial bag volume were assumed to be ±5 percent. The screening data from the DuPont study are shown in Table 2-10.

DuPont concluded from the data collected that no significant difference in leak frequency exists between manual and automatic control valves. Significant trends were observed with changes in product vapor pressure. It also seemed that full open or closed valve seat positions resulted in lower leak frequencies than intermediate positions.

2.1.5 Exxon Cyclohexane Study[18]

A fugitive emissions study was conducted by Exxon Chemical Company at the cyclohexane unit at their Baytown plant. The total number of valves, pump and compressor seals, and safety valves were determined. For all sources, except valves, all of the fugitive emission sources were sampled. For valves, a soap solution was used to determine leaking components. All leaking valves were counted and identified as either small, medium or large leaks. From the set of valves found to be leaking, specific valves were selected for sampling so that each class of leaking valves was in approximately the same proportion as it occurred in the cyclohexane unit.

Heat resistant mylar bags or sheets were taped around the equipment to be sampled to provide an enclosed volume. Clean metered air from the filter apparatus was blown into the enclosed volume. The sampling train was allowed to run until a steady state flow was obtained (usually about 15 minutes). A bomb sample was taken for laboratory analysis (mass spectrometry). Table 2-11 presents the results of the Exxon study.

2.1.6 EPA 24-Unit Study[19]

EPA coordinated a study in 1980 to develop information about fugitive emissions in the SOCMI. A total of 24 chemical process units were selected

TABLE 2-10. FREQUENCY OF LEAKS[a] FROM FUGITIVE EMISSION SOURCES IN TWO DuPONT PLANTS[b]

Equipment type	No. of leakers	No. of non-leakers	Percent leakers
Valves	48	741	6.1
Gas	35	120	23.1
Light liquid	11	143	7.1
Heavy liquid	1	478	0.2
Pumps	1	36	2.7
Light liquid	1	6	14.3
Heavy liquid	0	29	0

[a] Leak defined as 10 ppm or greater. Screening conducted with an OVA-108 calibrated with hexane.

[b] Source: Reference 20.

TABLE 2-11. FREQUENCY OF LEAKS[a] FROM FUGITIVE EMISSION SOURCES IN EXXON'S CYCLOHEXANE UNIT[b]

Equipment Source	Total in Unit	Screened and Sampled	Percent Leaking	Emission factor(kg/hr)	99.8% Confidence Interval (kg/hr)
Valves					
Gas	136	136	32	0.017[d]	0.008 - 0.035
Light Liquid	201	100	15	0.008[d,e]	0.003 - 0.007[e]
Safety Valves	15	15	87	0.064	0.013 - 0.5
Pump Seals[c]	8	8	83	0.255	0.082 - 0.818
Compressor Seals[c]	N/A	N/A	100	0.264	0.068 - 1.045

N/A - Not available.

[a] Leak defined as 10,000 ppm or greater. Monitoring instrument and calibration gas unknown.

[b] Source: Reference 21.

[c] Double mechanical seal pumps and compressors were found to have negligible leaks.

[d] Not clear whether these factors are kg VOC/leaking valve or kg VOC/valve.

[e] The values presented are direct conversions from the values given in the reference. There is an apparent typographical error.

for this purpose. The process units were selected to represent a cross-section of the population of the SOCMI. Several of the factors considered during process unit selection included annual production volume, number of producers, process conditions, corrosivity, volatility, toxicity, and value of the final products. Table 2-12 shows some of the factors considered in selection of process unit types. Several of the chemicals on the list are either carcinogens or suspected carcinogens: acrylonitrile, ethylene dichloride, formaldehyde, perchloroethylene and vinyl chloride.

The screening work began with the definition of the process unit boundaries. All feed streams, reaction/separation facilities, and product and by-product delivery lines were identified on process flow diagrams and in the process unit. Process data, including stream composition, line temperature, and line pressure, were obtained for all flow streams. Each process stream to be screened was identified and process data were obtained with the assistance of plant personnel, in most cases. Sources were screened by a two-person team (one person handling the hydrocarbon detector and one person recording data).

The Century Systems Models OVA-108 and OVA-128 hydrocarbon detectors were used for screening. The HNU Systems, Inc., Model PI 101 Photoionization Analyzer was also used to screen sources at the formaldehyde process unit. The detector probe of the instrument was placed directly on those areas of the sources where leakage would typically occur. For example, gate valves were screened along the circumference of the annular area around the valve stem where the stem exits the packing gland and at the packing gland/valve bonnet interface. All process valves, pump seals, compressor seals, agitator seals, relief valves, process drains, and open-ended lines were screened. From five to twenty percent of all flanges were randomly selected and screened. For the purpose of this program "flange" referred to any pipe-to-pipe or tubing-to-tubing connection, excluding welded joints.

Each screening instrument was calibrated on a daily basis, at a minimum. The model OVA-108 instruments, with logarithmic scales reading from 1 ppmv to 10,000 ppmv, were calibrated with high (8,000 ppmv) and low

TABLE 2-12. FACTORS CONSIDERED IN SELECTION OF TYPES OF PROCESS UNITS[a]
- 24 Unit Study -

Chemical Product	Production volume 10^9 lb/yr (1977)	Number of producers (1977)	Vapor pressure of product, mm Hg at 20°C	Threshold limit value[b] of product, ppmv	Cost of product, $/lb (1980)
Acetaldehyde	<1.7	5	760^+	100	0.29
Acetone	2.2	13	160.5	1000	0.30
Acrylonitrile	1.6	4	84.9	20(skin)	0.38
Adipic acid	1.5	5	<1.1	NA[c]	0.53
Cumene	2.6	14	3.3	50(skin)	0.27
Ethylene	25.4	31	760^+	NA[c]	0.24
Ethylene dichloride	11.0	12	60.2	10	0.14
Formaldehyde	6.0	16	760^+	2	0.07
Methyl ethyl ketone	0.5	5	76.2	200	0.35
Methyl methacrylate	0.7	3	28.1	100	0.50
Perchloroethylene	0.6	8	13.7	100(skin)	0.23
Phenol	2.3	13	<1.7	5(skin)	0.36
1,1,1-Trichloroethane	0.6	3	95.6	350	0.31
Trichloroethylene	0.3	5	57.0	100	0.27
Vinyl acetate	1.6	6	84.2	10	0.34
Vinyl chloride monomer	6.0	12	760^+	5	0.22

[a] Source: Reference 22.

[b] Eight-hour time weighted average.

[c] Threshold limit value not available or not established.

(500 ppmv) concentration methane-in-air standards to ensure accurate operation at both ends of the instrument's range. The model OVA-128 instruments, with linear readouts ranging from 0 ppmv to 1,000 ppmv, were also calibrated with high and low concentration standards. A pre-calibrated dilution probe was used with the OVA-128 when calibrating with the 8,000 ppmv standard.

The HNU Photoionization instrument, used to screen the formaldehyde process unit, was calibrated with isobutylene, which has an ionization potential close to that of formaldehyde.

Results of the screening program at the 24 process units are summarized in Table 2-13.

2.1.7 EPA's Position at Proposal

After considering the data available at proposal, EPA estimated fugitive emissions of VOC from SOCMI by using the emission factors developed in the study of fugitive emissions in petroleum refineries. The petroleum refinery data are the most comprehensive and definitive fugitive emissions data available and the study had been designed to produce emission factors which would estimate uncontrolled fugitive emissions of VOC. The use of petroleum refinery data to characterize emissions from SOCMI units was based on the position that equipment handling similar substances would behave similarly and therefore emissions from similar equipment in VOC service should be similar. The available SOCMI fugitive emissions data also supported this judgement. (Tables 2-14 and 2-15 show a comparison of the results of the studies of fugitive emissions available at the time of proposal.) Furthermore, the refinery fugitive emissions data were collected before an awareness of the magnitude of fugitive emissions became widespread, and, therefore, the petroleum refinery emission factors are considered representative of fugitive emissions in the absence of a leak detection and repair program. Thus EPA concluded that emissions from SOCMI in the absence of a leak detection and repair program could be estimated using emission factors developed for fugitive VOC emission sources in petroleum refineries.

TABLE 2-13. SUMMARY OF SOCMI PROCESS UNITS FUGITIVE EMISSIONS (24 Unit Study)[a]

Source Type	Service	(1) Number Screened	(2) % Not Screened	(3) % of Screened Sources with Screening Values >10,000 ppmv	(4) 95% Confidence Interval for Percentage of Sources >10,000 ppmv
Flanges	Gas	1,443	4.6	4.6	(3.6, 5.8)
	Light Liquid	2,897	2.6	1.2	(0.9, 1.8)
	Heavy Liquid	607	2.4	0.0	(0.0, 0.6)
Process Drains	Gas	83	23.1	2.4	(0.3, 8.4)
	Light Liquid	527	1.9	3.8	(2.3, 5.8)
	Heavy Liquid	28	0.0	7.1	(0.9, 23.5)
Open-Ended Lines	Gas	923	17.5	5.8	(4.4, 7.5)
	Light Liquid	3,603	10.4	3.9	(3.3, 4.6)
	Heavy Liquid	477	21.5	1.3	(0.5, 2.8)
Agitator Seals	Gas	7	46.1	14.3	(0.4, 57.9)
	Light Liquid	8	11.1	0.0	(0.0, 36.9)
	Heavy Liquid	1	66.7	0.0	(0.0, 97.5)
Relief Valves	Gas	85	72.7	3.5	(0.7, 10.0)
	Light Liquid	69	40.5	2.9	(0.3, 10.1)
	Heavy Liquid	3	66.7	0.0	(0.0, 70.8)
Valves	Gas	9,668	17.5	11.4	(10.8, 12.1)
	Light Liquid	18,294	12.2	6.4	(6.1, 6.8)
	Heavy Liquid	3,632	9.9	0.4	(0.2, 0.7)
Pumps	Light Liquid	647	4.3	8.8	(6.6, 11.1)
	Heavy Liquid	97	40.5	2.1	(0.3, 7.3)
Compressors	Gas	29	9.4	6.9	(0.9, 22.8)
Other[b]	Gas	19	9.5	21.0	(6.0, 45.6)
	Light Liquid	33	19.5	6.1	(0.7, 20.2)
	Heavy Liquid	2	33.3	0.0	(0.0, 84.2)

[a] Source: Reference 23.

[b] Includes filters, vacuum breakers, expansion joints, rupture disks, sight glass seals, etc.

TABLE 2-14. COMPARISON OF FUGITIVE EMISSION SOURCE LEAK FREQUENCIES AVAILABLE IN THE BID

Equipment Type	Percent of SOCMI Sources Having Screening Values >10,000 ppmv, OVA-108, Methane (six unit study)[a]	Percent of SOCMI Sources Having Screening Values >10,000 ppmv, OVA-108, Methane (24 unit study)[b,c]	Percent of Petroleum Refinery Sources Having >Screening Values 10,000 ppmv, TLV-Hexane[d]
Valves (all)	11		
Gas		11.4	10
Light Liquid		6.5	11
Heavy Liquid		0.4	0.2
Open-ended Lines (all)	10	4	7.7
Gas		5.9	
Light Liquid		3.9	
Heavy Liquid		1.3	
Pumps (all)	17		
Light Liquid		8.8	24
Heavy Liquid		2.1	2
Compressors (Gas)	10[e]	9.1	36
Pressure Relief Valves (all)	0	3	7
Gas		3.6	
Light Liquid		2.9	
Heavy Liquid		0.0	
Flanges (all)	3	2	0.5
Gas		4.6	
Light Liquid		1.3	
Heavy Liquid		0.0	
Process Drains (all)	N/A	4	5
Gas		2.4	
Light Liquid		3.8	
Heavy Liquid		7.1	
Agitator Seals (all)	N/A		N/A
Gas		14.3	
Light Liquid		0.0	
Heavy Liquid		0.0	

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[a] Source: Reference 24.

[b] Source: Reference 25.

[c] Values changed only slightly from the initial report (Docket No. IV-A-11) to the Analysis Report (EPA-600/2-81-111).

[d] Source: Reference 26.

[e] Value does not include the reciprocating compressors screened in a LD polyethylene unit.
Note: N/A means not available.

TABLE 2-15. COMPARISON OF EMISSION FACTORS AVAILABLE IN THE BID, kg/hr

Equipment type	Petroleum refinery study[a,b]	Exxon study[c]
Valves		
Gas service	0.0268	0.017[d]
Light liquid service	0.0109	0.008[d]
Heavy liquid service	0.00023	
Pump seals		
Light liquid service	0.114	0.255
Heavy liquid service	0.021	
Compressor seals (hydrocarbon service)	0.636	0.264
Pressure relief valves (all)	0.086	0.064
Gas service	0.16	
Light liquid service	0.006	
Heavy liquid service	0.009	
Flanges	0.00025	
Open-ended lines	0.0023	

[a] Source: Reference 27.

[b] The emission factors presented in the BID were based on an interim report (EPA-600/2-79-044); the values listed here represent the final published emission factors (EPA-600/2-80-075c).

[c] Source: Reference 28.

[d] Not clear whether these factors are kg VOC/hr/source or kg VOC/hr/leaking source.

2.2 NEW INFORMATION

Through the efforts of EPA and industry, several studies began on fugitive emission sources in SOCMI units during the development of the proposed standards. Since proposal, the results of these studies have been finalized. In addition, the results of fugitive emissions studies by industry in Germany and in a petrochemical unit in the United States became available. The nature and the results of these studies are summarized below.

2.2.1 German Studies on Fugitive Emissions[29]

Four interrelated studies conducted in West Germany investigated leakages from static and dynamic seals in chemical and petrochemical plants and methods of leak prevention. The sealing elements were classified as follows:

Static sealing elements
- flange connections
- manholes
- threaded connections

Dynamic sealing elements
- seals on oscillating machines (piston rod packing boxes on gas compressors and piston pumps)
- seals on rotating machines (slide ring seals on centrifugal pumps, agitators and centrifugal compressors, labyrinth packings on centrifugal compressors, seals for scaling liquid on centrifugal compressors, packing boxes on centrifugal pumps and agitators)
- seals on fittings and control valves (stuffing box)

Various procedures were employed for measurement of leak rates. The "pressure drop" method makes use of the measurement of the pressure drop of a pressurized and completely sealed sealing element. In the "pressure retention" method the pressure drop was compensated by injection of a measured quantity of gas. In the "capsule method" the seals were encapsulated with tape (for flanges) or globes (for valves). In the "spray method" the seal was sprayed with soap solution or another foam agent. The leakage was visible due to the formation of foam. The leak rate was estimated from the rate of bubble formation.

Qualitative statements were made by the studies about the dependence of leakages from static seals (primarily flanges) on physical, chemical, and design parameters, e.g. laminar capillary flow, pore diffusion in connection with contact pressure, the dimensions and properties of sealing rings, the overpressure of the fluid, etc. However, the studies pointed out that data were insufficient to permit a quantitative statement on the effects of changing or on more quantities. The number of parameters affecting dynamic seals was said to be even greater. As with static seals, quantitative relationships were determined for dynamic seals.

The leak rates for the sources investigated were estimated to be about 1/10 of the values found in previous German literature. The studies emphasized that valves showed many high leakage values; therefore, the average leak rate increased. It was further reported that before any directed maintenance of valves with high emission rates (i.e., screening values), the leak rates were 200 percent of the literature values. However, it was noted that regular maintenance of the valves reduced the average leak rates to below 10 percent of the literature values. One of the studies concluded that the most effective ways for avoiding excessive leak rates are to train carefully the operating and maintenance personnel and to use "maintenance-free" valves.

2.2.2 Union Carbide Study[30]

Union Carbide conducted a study of fugitive emissions at a SOCMI unit. The objective of the study was to find all leaking points in the process unit and to quantify their leak rates. A secondary objective was to develop a statistical fugitive emission sampling plan for future fugitive sampling work.

The potential leaking points were screened with Century Systems Model OVA-128 calibrated with hexane. Sources were screened at the surface. A leak was defined as a source screened at 1000 ppm or greater. Table 2-16 presents a summary of the leak frequencies found in the Carbide study.

A total of 1,569 points were screened. Pipe joints, hand valves, and valve bonnets accounted for 85 percent of the total sources. The overall leak frequency was 6.7 percent. Pumps had the highest leak frequency

TABLE 2-16. LEAK FREQUENCY IN UNION CARBIDE STUDY[a]

	Number Screened	Percent Leaking[b]
Safety/Relief Valves	26	0
Open-ended Lines	127	31
Gas	19	21
Liquid	108	32
Manholes	9	0
Valves - Total	484	7.2
Gas	120	6.7
Liquid	364	7.1
Hand	442	6.6
Motor	42	14
Pumps	18	39
Valve bonnets	279	0.7
Flanges	507	1.8
Threaded connections and compressed ferrules	112	8.9
Total	1569	Average 6.7

[a] Source: Reference 31.

[b] Leak defined as 1,000 ppm as measured by OVA-128 calibrated with hexane.

(39 percent). Since not all pumps were in operation during the screening study, the overall leak frequency reported may be slightly biased on the low side.

Leak rates were determined using different approaches depending on the boiling point, the temperature of the process fluid, and the extent of leakage as follows:

A: High leak rate, process fluid temperature low: The identified leaking point was enclosed and sealed completely with a plastic bag. Hydrocarbons saturated the enclosed bag and then condensed. The sampling time started when a layer of liquid condensed on the bag surface and the liquid started to run down the bag. After enough liquid accumulated, the bag was punctured and the liquid was collected in a bottle for weight determination.

B: Medium leak rate: First, the leak point was enclosed in a plastic bag. If no liquid condensation was observed in a few minutes, a tube was connected to the bag to remove the leaking hydrocarbons. The other end of the tube was connected to a condenser immersed in an ice bath. The majority of the hydrocarbons condensed in the condenser and the weight of the condensate was determined. The off-gas from the condenser was checked with a FID GC and negligible hydrocarbons were found for the few leaking points measured using this technique.

C: Low leak rate: After the leak point was enclosed in a plastic bag, two tubes were connected to the bag and a known flow rate of compressed air was introduced into the inlet tube. Gas samples were taken from the outlet tube and the concentration of hydrocarbons was determined with a FID GC.

Table 2-17 shows the leak rates found in the study with the leak rates broken down according to the extent of leakage. Table 2-17 shows that 25 percent of the top leakers accounted for 99 percent of the total emissions.

2.2.3 Maintenance Study[32]

A study of the effects of maintenance was performed concurrently with the twenty-four unit screening study described previously. The maintenance study was performed in six of the units studied in the twenty-four unit study. The primary purpose of this study was the evaluation of maintenance for fugitive VOC emissions control. The study yielded quantitative

TABLE 2-17. ESTIMATED FUGITIVE EMISSION LOSS IN THE UNION CARBIDE UNIT[a]

Extent of Leakage	Point leak rate, kg/hr/source	Estimated No. of leak points	Total leak rate, kg/hr/source	Wt. % of total Emissions
Small leak	0.00002-0.00037	50	0.01	0.07
Wet surface	0.0019-0.0005	30	0.1704	1.3
Dripping or unbearable odor	0.0188-0.3788	20	3.788	28.2
Continuous flow	0.9467-2.841	5	9.47	70.5
	Totals	105	13.44	100

[a] Source: Reference 33.

estimates of the effects of maintenance on fugitive emissions and leak occurrence and recurrence rates. As a secondary aspect of the study, correlations of screening values with emission rates were developed. The results of the study are discussed in detail in the section on emission reductions.

The three process types studied were ethylene, cumene, and vinyl acetate. Ethylene was chosen because typically these units are large and widespread, operate with a wide range of process conditions, and handle very volatile materials. Cumene was of interest because this type of unit handles benzene, which has been listed as hazardous under Section 112 of the Clean Air Act. Production of vinyl acetate from the reaction of ethylene and acetic acid was chosen because some of the process streams are corrosive. Two units of each process type were selected for the study. The units were judged to be representative of the current level of control existing in industry. One of the cumene units and one of the vinyl acetate units employed leak detection and repair programs. And pumps in one of the vinyl acetate units were equipped with dual seals and heavy liquid, positive pressure barrier fluid systems.

In order to study the effects of maintenance on fugitive emissions, valves and pump seals with various leak characteristics were to be studied in detail. The total number of sources studied in all process units in each category are given in Table 2-18. During the twenty-four unit screening studies, leaking sources at the six units selected for the maintenance studies had been tagged. The sources to be sampled were then selected at random from these sources identified in the screening study.

Screening was done with a Century Systems Corporation OVA-108 and a Bacharach TLV Sniffer. The valves were screened by traversing 360 degrees around the stem seal and the seam where the packing gland merges with the valve bonnet. The point of maximum concentration was identified. Pumps were screened at the outer shaft seals by completely traversing 360 degrees to locate the maximum concentration. Valve sampling was conducted by first screening the valves with the OVA-108 and TLV Sniffer. The screening values and time of day were recorded. Selected valves were then tented with Mylar

TABLE 2-18. MATRIX OF SAMPLING/SCREENING FOR ALL UNITS[a]

Stream Class	Initial Screening Value (ppm)	Number to be studied in each fitting type				
		Control Valves		Block Valves		Pump Seals
		M*	C**	M*	C**	C**
Gas	< 1,000	--	84***	--	161***	--
	1,000 to 9,999	11	4	14	10	--
	10,000 to 49,999	10	4	12	8	--
	≥50,000	13	7	14	11	--
Light Liquid	< 1,000	--	124***	--	165***	87
	1,000 to 9,999	14	5	19	10	11
	10,000 to 49,999	8	2	17	8	9
	≥50,000	13	6	18	9	6

[a] Reference 34.

M* is the number of valves actually maintained.

C** is the number of valves (or pumps) in the control group.

*** "low leaking" valves for Unit 1 could not be matched to their original process information since the identification tags were removed between the first and second visits. There were a total of 106 "low leaking" valves in Unit 1.

and duct tape and sampled. The tent was removed and the valve was rescreened. Pump sampling was analogous to valve sampling.

2.2.4 Analysis Report[35]

The results of the maintenance study were combined with the results of the 24-unit study for more in-depth analysis. The analysis report presents the findings of several data analysis tasks. Three of these tasks were the analysis of leak frequency as a function of process parameters, the emission factor development, and the analysis of leak frequency as a function of equipment design. Other analysis tasks contained in the report, including the impact of instrument response factors on leak frequency and the impact on mass emissions due to leak occurrence and recurrence (see Section 4), do not directly relate to emissions estimates and are not discussed here.

The process parameters that were examined for their effect on leak frequency were process type, service, material in line, line pressure, line temperature, and elevation of source. Data on four source types (valves, pump seals, flanges, and open-ended lines) were used to examine the effects of these parameters. As presented in Table 2-19, leak frequency for these source types varied among the 15 process types as well as with service type. And in almost every case examined, higher leak frequencies were associated with higher line pressures. Line temperature was found to have no consistent effect on leak frequency, while higher leak frequencies tended to be associated with higher ambient temperatures. The effect of ambient temperature, however, was not statistically significant in a majority of cases. Finally, the elevation of the source, that is the height above grade, had no consistent effect on leak frequency.

Emission factors were developed for gas valves, light liquid valves, and light liquid pumps for the three process types studied in the maintenance program. The sources included in the development of the emission factors were all valves and pump seals screened in the seven ethylene, cumene, and vinyl acetate process units or 51.2 percent of all valves and pump seals screened in the twenty-four unit screening program. Because leak rate/screening value models that were determined depend on the process type, emission factor estimation was limited to these

TABLE 2-19. PERCENT LEAKING FOR EACH CHEMICAL UNIT TYPE AS A FUNCTION OF SOURCE TYPE AND STREAM SERVICE IN SOCMI[a]

	GAS			LIGHT LIQUID			HEAVY LIQUID		
Source/Chemical (units)[b]	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking
Valves									
Vinyl Acetate (1,3)	949	35	3.7	2137	8	0.4	124	0	0
Ethylene (2,4,11)	6294	934	14.8	4176	969	23.2	1237	13	1.1
Cumene (5,6)	448	63	14.1	799	84	10.5	198	0	0
Acetone/Phenol (12)	8	0	0	1818	6	0.3	488	0	0
Ethylene Dichloride (21,29)	403	4	1.0	2256	24	1.1	----	----	----
Vinyl Chloride Monomer (20,28)	412	30	7.3	1209	12	1.0	----	----	----
Formaldehyde (22)	41	1	2.4	121	0	0	----	----	----
Methyl Ethyl Ketone (31,32)	207	19	9.2	671	34	5.1	----	----	----
Acetaldehyde (33)	178	8	4.5	551	3	0.5	----	----	----
Methyl Methacrylate (34)	190	0	0	1058	1	0.1	----	----	----
Adipic Acid (35,64)	95	0	0	17	0	0	1478	0	0
Chlorinated Ethanes (60, 62)	48	0	0	1620	10	0.6	12	0	0
Acrylonitrile (65,66)	396	9	2.3	1494	28	0.9	95	0	0
1,1,1-Trichloroethane (51)	----	----	----	373	4	1.1	----	----	----
Pump Seals									
Vinyl Acetate (1,3)	----	----	----	89	4	4.5	5	0	0
Ethylene (2,4,11)	----	----	----	76	20	26.3	15	0	0
Cumene (5,6)	----	----	----	25	4	16.0	3	0	0
Acetone/Phenol (12)	----	----	----	86	2	2.3	36	0	0
Ethylene Dichloride (21,29)	----	----	----	58	3	5.2	----	----	----
Vinyl Chloride Monomer (20,28)	----	----	----	65	7	10.8	----	----	----
Formaldehyde (22)	----	----	----	8	0	0	----	----	----
Methyl Ethyl Ketone (31,32)	----	----	----	31	1	3.2	----	----	----
Acetaldehyde (33)	----	----	----	32	3	9.4	----	----	----
Methyl Methacrylate (34)	----	----	----	45	2	4.4	----	----	----
Adipic Acid (35,64)	----	----	----	----	----	----	30	0	0
Chlorinated Ethanes (60, 62)	----	----	----	60	5	8.3	----	----	----
Acrylonitrile (65,66)	----	----	----	61	5	8.2	8	2	25.0
1,1,1-Trichloroethane (61)	----	----	----	10	1	10.0	----	----	----

(Continued)

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TABLE 2-19. (CONTINUED)

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	GAS			LIGHT LIQUID			HEAVY LIQUID		
Source/Chemical (units)[b]	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking
Flanges									
Vinyl Acetate (1,3)	107	3	2.8	173	0	0	8	0	0
Ethylene (2,4,11)	634	39	6.2	407	25	6.1	89	0	0
Cumene (5,6)	367	19	5.2	468	9	1.6	130	0	0
Acetone/Phenol (12)	----	----	----	82	0	0	30	0	0
Ethylene Dichloride (21,29)	25	1	4.0	163	1	0.6	----	----	----
Vinyl Chloride Monomer (20,28)	16	2	12.5	47	0	0	----	----	----
Formaldehyde (22)	2	0	0	8	1	12.5	----	----	----
Methyl Ethyl Ketone (31,32)	22	0	0	76	0	0	----	----	----
Acetaldehyde (33)	32	0	0	144	0	0	----	----	----
Methyl Methacrylate (34)	38	0	0	247	0	0	----	----	----
Adipic Acid (35,64)	49	0	0	2	0	0	320	0	0
Chlorinated Ethanes (60, 62)	16	0	0	461	0	0	2	0	0
Acrylonitrile (65,66)	142	2	1.4	382	0	0	28	0	0
1,1,1-Trichloroethane (61)	----	----	----	73	0	0	----	----	----
Open Ended Lines									
Vinyl Acetate (1,3)	145	8	5.5	318	8	2.5	22	2	9.1
Ethylene (2,4,11)	305	37	12.1	214	41	19.2	91	0	0
Cumene (5,6)	6	0	0	15	2	13.3	1	0	0
Acetone/Phenol (12)	2	0	0	518	8	1.5	107	0	0
Ethylene Dichloride (21,29)	100	0	0	475	16	3.4	----	----	----
Vinyl Chloride Monomer (20,28)	55	2	3.6	340	18	5.3	----	----	----
Formaldehyde (22)	14	0	0	36	0	0	----	----	----
Methyl Ethyl Ketone (31,32)	37	3	8.1	186	19	10.2	----	----	----
Acetaldehyde (33)	34	3	8.8	158	8	5.1	----	----	----
Methyl Methacrylate (34)	63	0	0	335	1	0.3	----	----	----
Adipic Acid (35,64)	19	0	0	1	0	0	214	0	0
Chlorinated Ethanes (60,62)	27	0	0	412	6	1.5	4	0	0
Acrylonitrile (65,66)	116	1	0.9	486	12	2.5	38	4	10.5
1,1,1-Trichloroethane (61)	----	----	----	111	2	1.8	----	----	----

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[a] Source: Reference 36.

[b] Unit numbers represent the unit number designation reported in the 24-Unit Study (Reference 37).

process units. These emission factors are shown in Table 2-20. (Note: These factors were recalculated at a later date.)

In addition to the above results, the pump and valve data were examined in closer detail for design-oriented effects. Control valves had a higher leak frequency than block valves. And for block valves, gate valves had the highest leak frequency, while plug and ball valves demonstrated the lowest leak frequencies. On-line pump seals had an overall leak frequency of 13.1 percent compared to 3.9 percent for off-line seals. Although no difference in leak frequency was found for dual mechanical and single mechanical pump seals, the barrier fluid composition was not known and could not be accounted for in the analysis.

2.2.5 Analysis of Allied HDPE Unit Data[38]

A 10-month study was performed by Allied and Kemron in Allied's newest existing high density polyethylene unit (HDPE). The study consisted of six screening and emissions measurement tests performed on valves and flanges over a 9-month period. EPA contracted a review of the data from this study.

A Century Systems Flame Ionization Analyzer (FIA), Model OVA-108 calibrated to 1000 ppm hexane was used in the screening studies. Calibration procedures differed from EPA's in that a high concentration standard was not used and the calibration was not verified at the end of the day. The leak frequencies determined in the six screening tests are shown in Table 2-21.

A tenting method was used to bag samples. Suspected fugitive emission points were enclosed in a Mylar tent. The source leak-rate was calculated from the amount of total hydrocarbons collected in a specific time period. The leak rates were determined only for sources screened at 10,000 ppm or greater and should not be compared with average emission factors. Table 2-22 shows the leak rates determined in the Allied study. The emission factors determined during the study were "leaker" emission factors. But some valves were maintained before being sampled. Therefore, the leaker emission factor presented is based on valves that had, in part, been subjected to a directed maintenance program.

TABLE 2-20. EMISSION FACTORS AND LEAK FREQUENCIES CALCULATED IN THE ANALYSIS REPORT WITH 95 PERCENT CONFIDENCE INTERVALS[a,b]

	Emission factor kg/hr	Leak[c] frequency, %
Gas Valves		
Vinyl Acetate	0.0021 (0.0004, 0.01)	3.7 (2, 5)
Cumene	0.0052 (0.001, 0.02)	16 (13, 19)
Ethylene	0.011 (0.004, 0.03)	15 (14, 16)
Light Liquid Valves		
Vinyl Acetate	0.0001 (0.00003, 0.001)	0.2 (0, 0.4)
Cumene	0.0025 (0.001, 0.01)	12 (10, 13)
Ethylene	0.010 (0.003, 0.03)	26 (24, 27)
Pump Seals (Light Liquid)		
Vinyl Acetate	0.0020 (0.00006, 0.06)	1.7 (0, 4)
Cumene	0.023 (0.0004, 1.2)	14 (1, 27)
Ethylene	0.031 (0.003, 0.4)	30 (20, 39)

[a] Source: Reference 39.

[b] These emission factors were later recalculated.

[c] Leak defined as 10,000 ppm or greater. Screening conducted with an OVA-108 calibrated with methane.

TABLE 2-21. LEAK FREQUENCY BY SOURCE AND SERVICE - HDPE UNIT[a]

		Liquid Service					
Source	Statistic	Test 1 (0)[b]	Test 2 (58)	Test 3 (110)	Test 4 (148)	Test 5 (190)	Test 6 (250)
Flanges	No. of leakers	69	72	47	71	31	33
	No. of sources tested	471	474	482	463	469	464
	Leak frequency, %	14.6	15.2	9.8	15.3	6.6	7.1
	LCL,[c] %	11.7	12.2	7.4	12.3	4.7	5.1
	UCL,[d] %	18.1	18.7	12.7	18.9	9.2	9.8
Valves	No. of leakers	54	47	22	34	26	28
	No. of sources tested	197	206	208	206	209	200
	Leak frequency, %	27.4	22.8	10.6	16.5	12.4	14.0
	LCL,[c] %	21.7	17.6	7.1	12.1	8.6	9.9
	UCL,[d] %	34.0	29.2	15.5	22.2	17.6	19.5
		Gas Service					
Flanges	No. of leakers	11	14	13	13	7	9
	No. of sources tested	149	146	148	169	173	175
	Leak frequency, %	7.4	9.6	8.8	7.7	4.0	5.1
	LCL,[c] %	4.2	5.8	5.2	4.6	2.0	2.7
	UCL,[d] %	12.7	15.5	14.4	12.7	8.1	9.5
Valves	No. of leakers	13	13	6	6	2	7
	No. of sources tested	74	71	74	77	76	76
	Leak frequency, %	17.6	18.3	8.1	7.8	2.6	9.2
	LCL,[c] %	10.6	11.0	3.8	3.6	0.7	4.5
	UCL,[d] %	27.8	28.8	16.6	16.0	9.1	17.8

[a] Source: Reference 40.

[b] The day number in parenthesis indicates the number of days from the end of Test 1 to the end of the specified test.

[c] Lower 95 percent confidence limit.

[d] Upper 95 percent confidence limit.

TABLE 2-22. LEAK RATES FOR LEAKERS BY SOURCE AND SERVICE - HDPE UNIT[a,b]

	Liquid Service	Gas Service
Source	kg/hr/source	kg/hr/souce
Flanges, mean	0.018	0.0059
LCL,[c] %	0.011	0.0036
UCL,[c] %	0.029	0.0100
No. tested[d]	70	20
Valves, mean	0.021	0.0022
LCL,[c] %	0.014	0.0012
UCL,[c] %	0.034	0.0039
No. tested[d]	56	7

[a] Source: Reference 41.

[b] Results were determined by Kemron bagging tests on a sample of 153 leakers (>10,000 ppmv). The bagging test data used in the analysis are in Appendix E of the report (Reference 41). The bagging test data not used (due to maintenance preceding the bagging test) are also in this appendix. These numbers are leak rates for leaking sources in the presence of a leak detection and repair program. The average magnitude of leak is decreased if maintenance has previously (successfully or unsuccessfully) applied.

[c] The lower (LCL) and upper (UCL) 95 percent confidence limits are determined by using a pooled estimate of the variance for the four data sets.

[d] The number of bagging tests by source and service.

2.2.6 SCAQMD Study[42]

A study of fugitive emissions in two petroleum refineries in the South Coast Air Quality Management District (SCAQMD) was undertaken by EPA to investigate the effectiveness of fugitive emission control regulations. The data were obtained by conducting leak detection surveys (screening) in selected units and by examining the refinery records pertaining to leak detection surveys conducted as requirements of the regulations. The effectiveness of the regulations, as determined by this study, is discussed later in the section on emissions reductions (Section 4).

A preliminary summary of the data collected in the two refineries is presented in the draft report. All accessible valves (with the exception of some heavy liquid valves), pumps, agitators, open-ended lines, drains, and relief valves in eight process units were screened with a Century OVA-108 hydrocarbon detector to identify the sources of fugitive VOC emissions. No flanges were screened. EPA Reference Method 21 was used for the screening surveys. In addition to the maximum hydrocarbon detector reading, certain information describing the source and its process conditions were recorded. This included the type of process unit, type of source, type of service, and the primary organic components in the line and their approximate concentrations.

A summary of the leak frequencies found in the refineries is presented in Table 2-23.

2.2.7 Coke Oven By-product Recovery Plant[43] and Gas Plant[44] Studies

Studies were conducted by EPA and industry groups to assess fugitive emissions from sources associated with coke oven by-product recovery plants and gas plants. The results of these studies are summarized in Tables 2-24 and 2-25.

Three coke oven by-product plants were tested by EPA for fugitive benzene emissions. Source screening was conducted using an OVA-108 portable hydrocarbon analyzer and was supplemented with measurements conducted using the TLV analyzer for sources that were sampled for mass emissions. The emissions data were categorized by source type and process stream benzene content. For some emission sources, emission factors were generated for

TABLE 2-23. SUMMARY OF LEAK FREQUENCIES BY SOURCE TYPE AND STREAM SERVICE IN TWO REFINERIES IN SCAQMD -- ALL PROCESS UNITS[a]

Source Type	Stream Service	Sources Subject to Rule			Sources Exempt from Rule		
		Number Screened	Number >10,000	Percent >10,000	Number Screened	Number >10,000	Percent >10,000
Open-Ended Lines	Gas	100	8	8.0	13	1	7.7
	Light Liquid	202	23	11.4	25	0	0.0
	Heavy Liquid	-	-	-	37	0	0.0
	Unknown	1	0	0.0	-	-	0
Sealed Open-Ended Lines	Gas	346	8	2.3	2	0	0.0
	Light Liquid	1019	41	4.0	22	0	0.0
	Heavy Liquid	-	-	-	25	0	0.0
Open Process Drains	Light Liquid	87	2	2.3	6	1	16.7
	Heavy Liquid	-	-	-	31	0	0.0
Relief Valves	Gas	7	1	14.3	-	-	-
	Light Liquid	12	0	0.0	-	-	-
	Heavy Liquid	-	-	-	2	0	0.0
Valves	Gas	2294	108	4.7	52	3	5.8
	Light Liquid	4761	274	5.8	175	3	1.7
	Heavy Liquid	-	-	-	284	0	0.0
Pumps	Light Liquid	116	20	17.2	17	0	0.0
	Heavy Liquid	-	-	-	40	0	0.0
Compressors	Gas	9	4	44.4	1	1	100.0
Others	Gas	1	0	0.0	-	-	-
	Light Liquid	11	0	0.0	-	-	-
TOTAL	Gas	2758	129	4.7	68	5	7.4
	Light Liquid	6208	360	5.8	245	4	1.6
	Heavy Liquid	-	-	-	419	0	0.0
	Unknown	1	0	0.0	-	-	-

[a] Source: Reference 45.

Note: Screening conducted with an OVA-108 calibrated with methane.

TABLE 2-24. LEAK FREQUENCY FOR SOURCES IN COKE OVEN BYPRODUCT UNITS[a]

Source	Number of Sources	Leak Frequency	Emission Factor, kg/hr/source (95% Confidence Interval)
Flanges[b]	66	0	-[c]
Threaded Connections[b]	59	0	-[c]
Valves[b]	135	5.9	0.015 (0.0013 - 0.14)
Pump Seals[b]	20	45	0.22 (0.054 - 0.75)
Exhausters[d]	34	8.8	0.015 (0.0003 - 0.042)

[a] Source: Reference 46.

[b] Sources were in service on process streams containing at least 10 percent benzene.

[c] Emission factors were not determined for these sources.

[d] These exhausters or compressors were mainly in hydrogen service.

TABLE 2-25. EMISSION FACTORS AND LEAK FREQUENCIES FOR FITTINGS IN GAS PLANTS[a]

Source	Number Screened	Percent Emitting[b]	Leak Frequency[c]	Total Emission Factor, kg/hr/source (95% Confidence Interval)
Connections & flanges	20,186	7.9	3.1	0.0011 (0.0004, 0.002)
Open-ended lines	1,560	26.8	11.9	0.022 (0.008, 0.04)
Pressure relief devices	107	40.2	17.5	0.19 (0.004, 4)
Valves	7,787	32.8	16.4	0.020 (0.008, 0.04)
Pump seals	137	73.0	29.7	0.063 (0.02, 0.2)
Compressor seals	71	74.6	52.8	0.20 (0.03, 1.3)

[a] Source: Reference 47.

[b] Percent emitting means the percentage of sources scoring above zero using soap scoring or instrument monitoring - API and EPA testing.

[c] Leak frequency means the percentage of sources screening at or above 10,000 ppm using instrument monitoring - EPA testing only.

nonmethane hydrocarbon emissions and benzene emissions. The leak frequencies and nonmethane hydrocarbon emission factors determined in this study are given in Table 2-24.

A total of six gas plants were screened in two studies: four by EPA and two by the American Petroleum Institute (API). The results of the combined studies are presented in Table 2-25. In both studies some of the sources identified as emitting were selected for leak rate measurement. There was a difference, however, in the screening technique used. The EPA study used portable hydrocarbon detectors, supplemented in many cases by soap bubble testing. The API study, on the other hand, relied primarily on soap bubble testing, employing a portable hydrocarbon detector where soap bubble testing was not possible. Using leak rate data collected during both studies, leak rates were estimated for all the emitting sources in both data sets to compute an emission factor for emitting sources alone. This factor was then adjusted to account for non-emitting sources by weighting the leak frequencies of emitting and non-emitting sources. These estimated total emission factors are presented in Table 2-25.

2.2.8 Revision of Emission Factors for Nonmethane Hydrocarbons From Valves and Pump Seals in SOCMI Processes[48]

The purpose of this report was to update nonmethane hydrocarbon emission factor estimates reported in the Analysis Report, based on further review of the available data and recently developed methodology.

Recent review of the emissions data used to develop emission factors for the vinyl acetate, cumene, and ethylene units indicated some differences in the screening value to emission relationships for valves, depending on whether maintenance had been performed on the valves during the screening study. In addition, the statistical methodology for estimating emission factors using screening data was refined. This methodology treats sources with screening values measured at or above 100,000 ppmv, i.e. censored data, separately from the sources with screening values which are not constrained. This approach minimizes biases from the censored data and results in more precise emission factor estimates.

The available data for valves were analyzed for leak rate/screening value relationships for each of the following groups:

1. All valves
2. Valves tested before maintenance was performed.
3. Valves tested after maintenance was performed.
4. Valves which were control sources (no maintenance performed).
5. Valves tested before maintenance and controls (2 and 4 combined).

The results of the analysis are summarized in Table 2-26. A significant effect of on-line maintenance on the screening value/leak rate relationship is seen. For valves in gas service the estimated leak rate (corresponding to a given screening value) for a valve tested before maintenance was performed was almost four times the estimate for a valve tested after maintenance. For valves in light liquid service the estimated leak rate for a valve tested before maintenance was performed is about two and one-half to three times greater than the estimated leak rate for a valve tested after maintenance.

The confidence interval for the modeled relationships indicated the statistical significance of the difference in the leak rate/screening value relationship for the before maintenance and after maintenance groups. The study concluded that the valves tested after on-line maintenance was done should not be used in developing models to estimate uncontrolled emission factors. The valves which were tested before maintenance and the valves used as control sources are appropriate for this purpose.

The OVA screening device used in the SOCMI emissions data collection efforts is designed to measure VOC concentrations up to 10,000 ppm. A dilution probe can be used to extend the scale to 100,000 ppm. A secondary dilution probe which allows concentration as high as 1,000,000 ppm to be measured was used in some cases in the maintenance study. But results obtained using two dilution probes are of questionable value due to the inaccuracies associated with measuring VOC concentrations of extremely small sample streams.

In developing regression equations to estimate leak rates from screening values in the maintenance study, those sources having screening

TABLE 2-26. ESTIMATED LEAK RATE TO SCREENING VALUE MODELS FOR GROUPS OF VALVES[a]

	Model Parameters[b]					Estimate of Leak Rate, kg/hr, (95 Percent Confidence Interval) for Different Screening Values		
Valves in Gas Service	n[c]	a	b	Correlation Coefficient	Standard Error	1,000 ppmv	10,000 ppmv	100,000 ppmv
Group 1 All Valves (EPA-600/52-81-080)	301	0.350	0.79	0.70	0.73	0.0009 (0.00046, 0.0014)	0.0055 (0.0041, 0.0064)	0.033 (0.027, 0.041)
Group 2 Before Maintenance	82	0.705	0.81	0.68	0.81	0.0018 (0.00091, 0.0036)	0.012 (0.0077, 0.019)	0.0077 (0.045, 0.13)
Group 3 After Maintenance	129	0.309	0.76	0.73	0.68	0.00046 (0.00036, 0.0091)	0.0036 (0.0027, 0.0045)	0.020 (0.014, 0.027)
Group 4 Controls	93	0.214	0.81	0.67	0.73	0.00046 (0.00027, 0.0014)	0.0036 (0.0027, 0.0055)	0.025 (0.018, 0.036)
Group 5 Before and Controls	175	0.427	0.81	0.67	0.78	0.00091 (0.00046, 0.0018)	0.0072 (0.0055, 0.0095)	0.045 (0.032, 0.064)
Valves in Light Liquid Service								
Group 1 All Valves (EPA-600/52-81-080)	350	5.27	0.54	0.55	0.83	0.0023 (0.0018, 0.0032)	0.0077 (0.0064, 0.0095)	0.028 (0.020, 0.035)
Group 2 Before Maintenance	104	11.5	0.50	0.49	0.78	0.0036 (0.0018, 0.0068)	0.011 (0.0077, 0.016)	0.036 (0.023, 0.055)
Group 3 After Maintenance	169	3.32	0.53	0.57	0.79	0.0014 (0.00091, 0.0018)	0.0041 (0.0032, 0.0055)	0.015 (0.010, 0.023)
Group 4 Controls	78	8.45	0.535	0.52	0.94	0.0032 (0.0018, 0.0068)	0.021 (0.0073, 0.019)	0.040 (0.021, 0.073)
Group 5 Before and Controls	182	9.05	0.53	0.52	0.86	0.0036 (0.0023, 0.0055)	0.021 (0.0091, 0.016)	0.041 (0.028, 0.059)

[a] Source: Reference 49.

[b] Model is of the form leak rate = a (10^{-5})(OVA Reading)^{b}

[c] Number of test rate/screening valve pairs; the numbers do not add to the total because of missing descriptor codes for some of the data pairs.

values higher than 1,000,000 ppm were treated as if the screening value was 100,000 ppm. This study made use of a recently developed statistical methodology for estimating emission factors which treats those censored sources separately from the uncensored screening values. This procedure deletes the censored sources in the regression analysis, and develops an estimate for censored sources using the deleted data. It also eliminates the potential bias of using those censored sources in the regression analysis.

Using the two changes in methodology described in the report, emission factors for valves and pump seals in ethylene, cumene, and vinyl acetate units were developed and are shown in Table 2-27.

2.3 PUBLIC COMMENT

Several commenters disagreed with using petroleum refinery emission estimates for SOCMI emission estimates. The commenters made three major points.

1. Commenters argued that both leak frequencies and mass emission rates for SOCMI fugitive emission sources are lower than those corresponding values for refinery sources. The commenters further felt that the lower leak tendencies of SOCMI had been shown in SOCMI studies. Studies cited included the twenty-four unit screening study,[50] the maintenance study,[51] the analysis report,[52] and the 4-unit EPA study,[53] which were previously discussed. The commenters felt, therefore, that SOCMI data should be used instead of refinery data to estimate emissions.

Also presented as evidence of lower fugitive emissions in SOCMI were results of studies performed by chemical companies in their own plants. Testing in an acrylonitrile unit was reported to yield emission rates of 0.0002 to 0.011 kg VOC/hr for pumps and 0.0002 to 0.0087 kg VOC/hr for valves. Emissions measured from a flange were 0.0003 kg VOC/hr. Leak frequencies determined in the acrylonitrile plant were 5.9 percent for light liquid pumps and 0.9 percent for light liquid valves.[54] Another inplant fugitive emissions testing project conducted in a chlorinated hydrocarbons unit was reported to yield pump emission rates of 0.0068 to 0.0095 kg VOC/hr.[55]

TABLE 2-27. REVISED EMISSION FACTOR ESTIMATES FOR NONMETHANE HYDROCARBONS FROM VALVES AND PUMP SEALS IN ETHYLENE, CUMENE, AND VINYL ACETATE UNITS[a]

kg/hr/source

Source Type	Emission Factor (95 Percent Confidence Interval)
Valves	
Gas service	
Ethylene	0.0086 (0.005, 0.012)
Cumene	0.007 (0.003, 0.016)
Vinyl Acetate	0.0014 (0.0005, 0.004)
Light Liquid Service	
Ethylene	0.018 (0.01, 0.03)
Cumene	0.006 (0.003, 0.013)
Vinyl Acetate	0.00023 (0.0001, 0.0006)
Pump Seals	
Light Liquid Service	
Ethylene	0.058 (0.01, 0.26)
Cumene	0.018 (0.0014, 0.22)
Vinyl Acetate	0.002 (0.0002, 0.01)

[a] Source: Reference 56.

2. Industry commenters said that differences between SOCMI and petroleum refining units could logically be expected to result in different levels of emissions. A primary reason given for the expected differences in emission factors was the dependence of emissions on the chemicals being processed. The commenters said that process streams having different compositions and, therefore, different chemical and physical properties will probably produce different emission factors. One of the specific reasons cited for differences in properties of refinery and SOCMI streams was higher polarity as a result of substitution of heteroatoms (Cl, O, N) for hydrogen. This polarity was seen as causing larger dipole moments and stronger bonds than those encountered in non-polar materials. Hydrogen bonding was also suggested as a cause of increased polarity. The polarity was seen as especially important because the more polar a substance is, the more difficult it is to volatilize.

Several other reasons for expected differences in emissions between the two industries were given. Many SOCMI materials were seen as more toxic and hazardous than refinery products. Industry commenters said that the toxicity of SOCMI chemicals often controls design and operating practices. As a result, SOCMI units were seen as better controlled than refineries with respect to fugitive emissions, and this level of control was expected to be reflected in lower leak frequencies and emissions.

It was also pointed out that the chemical industry to a large extent is characterized by smaller equipment and more batch processes that lend themselves more readily to improved fugitive emission control. Conversely, refineries were characterized by much more strenuous conditions, larger equipment, higher temperatures, and more outdoor continuous processes. This difference was also seen as contributory to the expected differences in emissions between the industries.

Finally, the materials produced in SOCMI were noted as of greater value than those produced in refineries. This increased value was seen as incentive for fugitive losses to be kept under better control in SOCMI than in petroleum refineries.

3. Industry commenters advocated the use of SOCMI emission factors when SOCMI factors were available. In fact, one comment letter contained emissions estimates that employed a weighted average of the SOCMI emission factors presented in the Analysis Report previously discussed.[57] The average was weighted 40 percent for ethylene, 30 percent for cumene, and 30 percent for vinyl acetate. The commenters used emission factors for gas valves, light liquid valves, and light liquid pumps from the Analysis Report, and petroleum refinery emission factors for the remaining emission sources. The factors used for the estimates are shown in Table 2-28.

2.4 EPA's CONCLUSIONS

2.4.1 Approach

In making a decision concerning what data to use in estimating fugitive emissions of VOC from SOCMI, EPA identified three major criteria which would form the basis for the decisions. The first criterion was relevance to estimating fugitive emissions from SOCMI. That is, the information considered had to be applicable to emissions of VOC from fugitive emission sources. The second criterion was validity of the testing and analytical methods used. Only those studies based on sound experimental design and implemented with valid testing and analytical methods could be considered. The third criterion was one of comparability to other work. The studies considered had to be comparable to other studies to allow validation of results by comparison with other studies. If a comparable basis for comparison could not be found, it would be impossible to judge whether the results of a particular study appeared reasonable in light of the results of other studies.

Available data upon which emissions estimates could be based have been presented previously in this section. Numerous studies of fugitive emissions were evaluated for use in developing emission estimates for SOCMI. As discussed earlier, six of these studies were considered prior to proposal and nine additional studies have been considered as discussed in Section 2.2. The results of these studies of fugitive emissions are compared in Tables 2-29 and 2-30.

TABLE 2-28. EMISSION FACTORS USED BY INDUSTRY COMMENTERS TO ESTIMATE EMISSIONS FROM SOCMI UNITS[a]

Equipment Component	Estimated Emission Factor kg/hr/source
Pump Seals	
Light Liquid	0.0020
Heavy Liquid	0.0200
In-Line Valves[b]	
Vapor	0.0065
Light Liquid	0.0045
Heavy Liquid	0.0003
Compressor Seals	0.441
Flanges	0.0003

[a] Source: Reference 58.

[b] Includes: safety relief valves, open-ended valves & lines, and sampling connections.

TABLE 2-29. SUMMARY OF AVAILABLE DATA ON FUGITIVE VOC EMISSION SOURCES - EMISSION FACTOR, kg/hr/source

Emission Source	Data Source							
	Petroleum Refinery Study[a]	4-Unit SOCMI Study[b]	Exxon Cyclohexane Study[c]	6-Unit Maintenance Study[d]			Coke Oven Study[e]	Gas Plant Study[f]
				Ethylene	Cumene	Vinyl Acetate		
Valves								
Gas	0.028		0.017	0.0086	0.007	0.0014		
Light Liquid	0.0109		0.008	0.018	0.006	0.00023		
All		0.037* 0.0045**					0.015	0.020
Pumps								
Light Liquid	0.114			0.058	0.018	0.002		
Heavy Liquid	0.021							
All		0.073* 0.022**	0.255				0.22	0.063
Compressors	0.636	0.035*	0.264				0.015	0.20
Safety/Relief Valves								
Gas	0.16							
All	0.086	0.0143* 0.0051**	0.064					0.19
Flanges	0.00025	0.045* 0.0014**						0.0011
Open-ended Lines	0.0023	0.091* 0.040*						0.022
Sampling Valves	0.015							

*Value for leaking source only.
**Average value.

[a] Source: Reference 59.
[b] Source: Reference 60.
[c] Source: Reference 61.
[d] Source: Reference 62.
[e] Source: Reference 63.
[f] Source: Reference 64.

TABLE 2-30. SUMMARY OF AVAILABLE DATA ON FUGITIVE VOC EMISSION SOURCES - LEAK FREQUENCY

Emission Source	Petroleum Refining Study[a]	4-Unit SOCMI Study[b]	6-Unit Screening Study[c]	DuPont Study[d]	Exxon Cyclohexane Study[e]	24-Unit Screening Study[f]	Union Carbide Study[g]	Allied HDPE Study[h]	SCAQMD Study[i]	Coke Oven Study[j]	Gas Plant Study[k]
Valves											
Gas	10			23.3	32	11.4	6.7	17.6	4.7		
Light Liquid	11			7.1	15	6.5		27.4	5.6		
All		7	11	6.1		8.2	7.2	24.7	5.1	5.9	16.4
Pumps											
Light Liquid	24			14.3		8.8			15.0		
Heavy Liquid	2			0		2.1			0		
All		23	17		83		39		11.6	45	30
Compressors	36		43			9.1			50	8.8	53
Safety/Relief Valves	7		0			3.2	0		4.8		17.5
Flanges	0.5	2	3			2.1		1.8		0	3.1
Open-ended Lines	7.7		10			3.9	31		8.5 3.5*		11.9

*Sealed open-ended lines.

[a] Screening conducted with TLV Sniffer using hexane calibrant and 10,000 ppm leak definition. Reference 65.

[b] Screening conducted with OVA-128 using the major constituent in the process stream as the calibrant and a 200 ppm equivalent methane leak definition. Reference 66.

[c] Screening conducted with OVA-108 using methane calibrant and 10,000 ppm leak definition. Reference 67.

[d] Screening conducted with OVA-108 using hexane calibrant and 100 ppm leak definition. Number for "all" includes heavy liquid valves. 0.2 percent of the heavy liquid valves were found leaking. Reference 68.

[e] Leak definition was 10,000 ppm with an undefined instrument and calibrant. Soap screening used for valves. Reference 69.

[f] Screening conducted primarily with OVA-108 and OVA-128 using methane calibrant and 10,000 ppm leak definition. Reference 70.

[g] Screening conducted with OVA-128 using hexane calibrant and 1,000 ppm leak definition. Reference 71.

[h] Screening conducted with OVA-108 using hexane calibrant and 10,000 ppm leak definition. Reference 72.

[i] Screening conducted with OVA-108 methane calibrant and 10,000 ppm leak definition. Reference 73.

[j] Screening conducted primarily with OVA-108 using hexane calibrant and 10,000 ppm leak definition. Reference 74.

[k] Screening conducted with OVA-108 using methane calibrant and 10,000 ppm leak definition. Supplemental data (reported in Table 2-) was provided using soap scoring. Reference 75.

After examining the available fugitive emissions data, it is apparent that no single, clear-cut set of emission factors from any one study can be applied to SOCMI. There are no mass emissions data which can be considered representative of emission factors for SOCMI as an industry. Furthermore, close scrutiny of the leak frequency data available showed that many of the studies were not comparable and could not be combined into one data set because of differences in leak definitions, different monitoring instruments calibrated with different gases, and different monitoring methods.

2.4.2 Evaluation of Fugitive Emissions Information

A summary of the data sets available on fugitive emissions is presented in Table 2-31 with strengths and weaknesses of the data noted.

The most complete and comprehensive work on fugitive emissions available prior to proposal was the study of emissions from petroleum refineries.[76] The data compiled in this study came from testing of over 64 units in 13 refineries. The units represented a broad cross-section of sizes and ages. In addition to the determination of leak frequencies for a number of fugitive emission sources, non-methane leak rate correlations were developed which allowed average emission factors to be determined for these sources.

The four-unit EPA study considered too small a number of sources and units to be considered valid for emission factors by itself. A subsequent study by EPA in six SOCMI process units[77] gave some useful results in terms of leak frequency only, with no mass emissions measurements made. These data were also limited in that the service (gas, light liquid, heavy liquid) of each source was not identified.

The four studies performed by industry which were available have limitations with regard to their quantitative results. The leak frequency for valves in the Exxon study of fugitive losses in a cyclohexane unit[78] was determined using a soap solution. And the mass emissions rate for valves was based on selective sampling of valves from qualitative leak rate categories (high, medium, and low leak). Further, the leak definition for all sources was not specified. Only pumps and valves were screened for leak frequency determination in the DuPont study.[79] Although the monitoring

TABLE 2-31. SUMMARY OF ASPECTS OF FUGITIVE EMISSIONS STUDIES

Study	Remarks	AID Section
Petroleum Refinery Study[80]	1. Emission factor and emitter[a] frequency determined. 2. Emission factor and frequency (emitter and leak) given by source and service. 3. Cross-section of refinery units. 4. "Uncontrolled" fugitive emissions data collected.	2.1.1
4-Unit EPA Study[81]	1. Limited data base for test design (4 units). 2. Leak definition of 200 ppm used for study. 3. Several sources considered for emission factor and emitter[a] frequency. 4. Leaking source emission factors determined. 5. Average emission factors estimated.	2.1.2
6-Unit Screening Study[82]	1. No emission factor determined. 2. Six sources[b] considered for leak frequency. 3. No delineation of sources by service (gas, light liquid, heavy liquid).	2.1.3 4.1.1
DuPont Study[83]	1. No emission factors determined. 2. Only valves and pumps studied for frequency of emissions. 3. Two older process units - limited data base. 4. Leak definition unspecified.	2.1.4
Exxon Cyclohexane Study[84]	1. Single unit study - limited base. 2. Four fugitive emission sources; valves by service. 3. Emission factor and percent of leaks determined. 4. Emissions rate for valves by "selected" valve distribution. 5. Leak definition for 3 sources was 200 ppm. 6. Leaking valves determined by soap solution.	2.1.5

TABLE 2-31. (CONTINUED)

Study	Remarks	AID Section
24-Unit Screening Study[85]	1. No emission factor determined. 2. Leak frequency[b] by source and service. 3. Cross-section of SOCMI represented for leak frequency[b].	2.1.6
German Study[86]	1. Leak rates determined for sealing mechanisms various means. 2. Qualitative results noted for seals (the importance of maintenance in reducing emissions from seals).	2.2.1
Union Carbide Study[87]	1. Leak definition of 1000 ppmv used. 2. Leak rates were categorized by quantity of emission, not by source. 3. Only a single unit was surveyed.	2.2.2
6-Unit Maintenance, Analysis and Revisions[88,89,90]	1. Emission factor for three processes - six units. (Subset of 24-unit results). 2. Emission factor for three fugitive emission source typess.	2.2.3 2.2.4 2.2.8 4.1.2 4.2.2
Allied HDPE Study[91]	1. Maintenance-oriented study. 2. Only valves and flanges studied. 3. Only leak emission factors determined.	2.2.5 4.1.2
SCAQMD[92] Maintenance Study (Preliminary)	1. Maintenance-oriented study - no mass emissions studied. 2. Leak frequencies[b] evaluated in two refineries. 3. Five sources with pumps and valves by service. 4. Limited data base for compressors and safety valves.	2.2.6 4.1.2 4.2.2

TABLE 2-31. (CONTINUED)

Study	Remarks	AID Section
Coke Oven and Gas Plant Studies[93,94]	1. Emission factors and leak frequencies determined. 2. Limited number of units surveyed and sources investigated. 3. Service not specified. 4. Various methods used in source screening.	2.2./

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[a] An emitter was defined as a source with a screening value >200 ppm.

[b] Leak frequency was based on a leak definition of 10,000 ppm.

instrument used (OVA-108) was of the same type used in the more recent EPA studies, an action level of 10 ppm was used to determine leaking sources. Likewise, the Union Carbide study was based on OVA measurements (OVA-128) at a different action level (1000 ppmv).[95] Although this study presented detailed analysis of leak frequency as a function of many variables (valve types, service, location, temperature, pressure, etc.), the applicability of the results to SOCMI in general is questionable since the study was conducted in only a single process unit. The primary result of the series of German studies was the effectiveness of good maintenance programs in reducing fugitive VOC emissions on a qualitative basis.[96]

The final study available before proposal was a screening study of 24 SOCMI process units[97] conducted to determine leak frequencies for a number of fugitive emission sources. The units were selected to represent a cross-section of the SOCMI population. They were not randomly chosen. Therefore, the units may or may not be representative of a true distribution of SOCMI units. No mass emissions testing was conducted during this study.

Subsequent studies completed after proposal provided further insight into the fugitive emissions from SOCMI. Non-methane leak rate functions were developed in the SOCMI Maintenance report.[98] In the SOCMI Analysis Report,[99] these functions were used with screening value distribution data to establish emission factors. Only three process units and three emission sources were studied, however, thus limiting the utility of the emissions rate data in describing emissions from SOCMI in general. These factors were later revised to account for some previous biasing due to maintenance.

The study conducted at an Allied HDPE unit[100] was primarily focussed on determining maintenance effects on valves and flanges. Although the leak frequencies measured may be valid and applicable, the emissions rates determined in this report were represented as emissions from leaking sources only. But some valves were maintained before they were sampled. The emission factors, therefore, cannot be directly compared to those determined for sources in SOCMI and petroleum refinery units because they represent valves which had, in part, been subjected to a maintenance program.

Several studies have been conducted to establish the effects of maintenance on leak frequency and rate for valves in petroleum refineries. Of these, the most recent was conducted by EPA to examine the effect of fugitive emissions rules on emissions from refineries in the South Coast Air Quality Management District (SCAQMD) in California.[101] No mass emissions data were collected in this study. But leak frequencies were measured for several types of fugitive emissions sources. Only a small amount of data was collected on compressors and safety/relief valves.

Although a large number of studies are available on fugitive emissions, many of the studies had to be eliminated from rigorous consideration for the purposes of estimating fugitive emissions of VOC from SOCMI. Incomplete data is the primary limiting factor in most of the studies available. As noted from the previous discussion, much of the leak frequency data could not be incorporated in a quantitative analysis due to the leak definition chosen or the lack of specificity in categorizing sources by service. Similarly, some of the emission factor data could only be applied qualitatively since they represented only leaking sources or, as in the case of the maintenance studies, included effects of attempted repair.

The two most complete studies of fugitive emissions of the studies available are the twenty-four unit screening study[102] and the petroleum refinery study.[103] The petroleum refinery study provides the most complete set of emission factors for fugitive emission sources. The twenty-four unit study, while it may not represent a true distribution of leaks in SOCMI, does represent a cross-section of the industry and was more comprehensive than other screening studies. These two studies were selected as the best studies on which emission estimates could be based.

2.4.3 Conclusions

Summary of Conclusions -- In the BID, estimates of VOC emissions are based on a comprehensive study of fugitive emission sources within petroleum refineries. When the standards were proposed, EPA considered data for fugitive emission sources within SOCMI. However, these data were not used in making emission estimates because EPA did not gather the data for determining emission factors, and EPA did not consider them representative of the industry.

In contrast, commenters requested that these data and other new data be used in making emission estimates for this industry. EPA agrees that these data could be used to estimate the percent of fugitive emission sources which leak. EPA continues to believe, however, that data from petroleum refineries are appropriate for estimating the quantity of VOC emissions from sources which leak, except for valves in gas service. The percent of fugitive emission sources which leak and the quantity of VOC emissions from sources which leak are the primary factors which influence the quantity of VOC emissions from fugitive emission sources.

Average Unit Concept -- Review of the available data on fugitive emissions from SOCMI indicated considerable variability among the process units tested (see Table 2-19). This variability is consistent with EPA's understanding of the nature of the group of industries which make up the SOCMI industry category. In an industry category composed of production facilities for chemicals, no one type of process unit could be considered typical. However, estimation of national impacts is dependent on the extrapolation of emissions from a typical unit to the entire U.S. population of units in SOCMI. Therefore, it is necessary to generate a single set of emission factors which can be considered as an "industry average". The situation is similar to the one found in the petroleum refining industry. Just as in the SOCMI units tested, wide variability was seen in the emissions from different units in the refineries tested (see Tables 2-2 through 2-6). EPA uses a single set of emission factors to represent an "average" refinery even though in reality an "average" refinery may not exist. In the same manner EPA decided to generate a set of emission factors which represent an "average" SOCMI unit.

Development of Emission Factors -- As indicated earlier (p.2-56), EPA determined that the best studies on which emission estimates for SOCMI emission sources could be based were the Petroleum Refinery Study[104] and the Twenty-four Unit Study.[105] Also indicated earlier, EPA considered these data sets to show differences between the SOCMI data and the petroleum refinery data. The assessment of differences and similarities between the data sets was not clearcut. There were some apparent differences, but they could not be explained conclusively. The differences may be due to factors mentioned by the commenters. It is impossible to tell because there are so many variables. It seemed illogical that on the average, identical equipment handling similar organic compounds would behave differently. However, EPA determined that the differences, as indicated by the data, were evident. Because of the differences, EPA decided that an adjustment of the emission factors used in the BID is warranted.

Reviewing the available studies of fugitive emissions from SOCMI units, no studies were found that resulted in a full set of emission factors applicable to SOCMI in general. Furthermore, no study had been designed to establish a single set of emission factors for SOCMI fugitive emission sources. Therefore, the results of more than one study would be needed to estimate fugitive emissions from SOCMI in general. Several approaches were considered for estimating emissions from SOCMI, in addition to the approach in the Background Information Document[106], including the following:

Approach 1 - applying a ratio of leak frequencies (SOCMI to refinery) to the refinery factors to obtain SOCMI factors;

Approach 2 - applying SOCMI leak frequencies to a correlation of emission factors versus leak frequency generated from SOCMI and refinery data;

Approach 3 - presenting a range of emission factors based on available SOCMI factors and factors generated from ratios of leak frequencies applied to refinery factors;

Approach 4 - determination of leaking source and non-leaking source emission factors from the refinery data set (as often as technically reasonable) and applying these factors to SOCMI leak frequencies to yield SOCMI factors for an average unit;

Approach 5 - using a weighted average of the available SOCMI factors as the average industry emission factor for those three sources (pump seals, gas valves, and light liquid valves) and refinery factors for the remaining sources.[107]

After considering these alternative approaches, EPA concluded that the best method of arriving at a complete set of emission factors was by using leak frequencies determined in the 24-unit study[108] to weight the emission factors determined in the petroleum refinery studies (Approach 4).[109] The approach of averaging emission factors from three types of SOCMI units suggested by commenters (Approach 5) was not chosen because the average of those three unit types is not representative of an average for SOCMI. Also, the level of existing control in the units tested was undetermined. Furthermore, emission factors from only three types of emission sources resulted from this approach. Approach 1 was not chosen because the ratios constructed in this manner included some with zeros in the denominator. Approach 2 was discarded because the correlation was not strong enough to make inferences. The third approach was discarded because ranges would be too unwieldy when carried through aggregation for the decision making process.

The approach chosen makes use of the two most comprehensive sets of fugitive emissions data available at this time. "Leaking source" emission factors and "non-leaking source" emission factors can be estimated from the complete petroleum refinery studies and leak frequency data (including leaking/non-leaking source distributions) representing a cross-section of SOCMI was available from the 24-unit screening study. Based primarily on these data sets, emission factors for an average SOCMI unit were computed by weighting the petroleum refinery emission factors. The manner in which this weighting was accomplished is described in the following paragraphs.

When a group of sources leak (screening value $\geq$10,000 ppm), they leak on the average at a certain mass rate. Likewise, those sources not leaking (screening value <10,000 ppm) have a certain average mass emission rate associated with them. Overall emission factors for emission sources, then, are a combination of two components: emissions due to leaking sources and emissions due to non-leaking sources.

Following this approach, emission factors for leaking sources (LEF) and emission factors for sources not leaking (NLEF) were determined for fugitive VOC emission sources using data from the petroleum refinery studies.[110] The leak/no leak factors were computed according to the following equations:

$$\text{LEF} = \frac{\text{OEF} \times \text{PCM}}{\text{PCL}} \quad \text{and} \quad \text{NLEF} = \frac{\text{OEF} \times (100 - \text{PCM})}{(100 - \text{PCL})}$$

where: LEF = emission factor for leaking sources
NLEF = emission factor for sources not leaking
OEF = overall emission factor
PCM = percent of mass emissions due to leaking sources
PCL = percent of sources found leaking

The development of the LEF and NLEF factors is presented in Table 2-32. The emission factors determined for SOCMI using leak/no leak emission factors from petroleum refineries in combination with leak frequencies determined in SOCMI[111] are shown in Table 2-33.

The emission factor development for two of the fugitive emission sources deserves specific comment. The emission factor for sampling connections is based on the amount of sampling purge reported for every 1,000 barrels of refinery throughput[112] and the average count of sampling connections per 1,000 barrels of refinery throughput reported.[113] The ratio of these values results in an emission factor of 0.0150 kg/hr/source. The emission factor for open-ended lines, represents valve seal leakage only. The emissions attributable to the valve, such as from around the stem and packing, are normal valve leakage and are accounted for in the valve emission factor. In the BID,[114] the emission factor for open-ended valves included contributions to emissions from the valve and the leakage through the seat. This combination was confusing and was therefore changed as explained in Chapter 3.

These "average" SOCMI emission factors were then compared to the emission factors determined for light liquid pumps, light liquid valves, and gas valves in seven actual SOCMI units.[115] The comparison is shown in Table 2-34.

It can be seen from the comparison of light liquid pump emission factors that the average SOCMI factor is lower than the factors for refineries and ethylene units and higher than the factors for cumene and vinyl acetate. The heavy liquid pump emission factors are the same for the average SOCMI unit and refineries.

TABLE 2-32. DEVELOPMENT OF EMISSION FACTORS FOR LEAKING AND NON-LEAKING SOURCES BASED ON REFINERY FUGITIVE EMISSIONS DATA (kg/hr/source)

Equipment	Service	Emission Factor[a]	Percent of Sources ≥10,000 ppm[a]	Percent of Emissions from Sources ≥10,000 ppm[a]	Leaker (>10,000 ppm) Emission Factor[b]	Non-Leaker (<10,000 ppm) Emission Factor[c]
Valves	Gas	0.0268	10	98	0.2626	0.0006
	LL[d]	0.0109	11	86	0.0852	0.00171
	HL[e]	0.00023	0.2	0.04	0.00023[f]	0.00023
Pump Seals	LL	0.114	24	92	0.437	0.0120
	HL	0.021	2	37	0.3885	0.0135
Compressor Seals	Gas	0.636	36	91	1.608	0.0894
Pressure Relief Valves	Gas	0.16	7	74	1.691	0.0447
Flanges	All	0.00025	0.5	75	0.0375	0.00006
Open-Ended Lines	All	0.0023	7.7	40	0.01195	0.00150

[a] From Appendix B of the finalized refinery assessment report (EPA-600/2-80-075c). Reference 116.

[b] Emission factor times the ratio of percent of mass emissions: percent of sources screening ≥10,000 ppm.

[c] Emission factor times the ratio of percent of mass emissions: percent of sources screening <10,000 ppm.

[d] LL - light liquid service.

[e] HL - heavy liquid service.

[f] Leaking emission factor assumed equal to non-leaking emission factor since the computed leaking emission factor (0.00005 kg/hr/source) was less than non-leaking emission factor.

TABLE 2-33. DEVELOPMENT OF AVERAGE SOCMI EMISSION FACTORS

	# Sources[1] Per 1000	Emission[2] Factor (kg/hr)	Emissions per 1000 (kg/hr)	Overall Emission Factor (kg/hr)
Pump Seals: Light Liquid				0.0494
Leak	88	0.437	38.5	
Non-Leak	912	0.012	10.9	
Total			49.4	
Heavy Liquid				0.0214
Leak	21	0.3885	8.20	
Non-Leak	979	0.0135	13.20	
Total			21.40	
Valves: Gas				0.0304
Leak	114	0.2626	29.9	
Non-Leak	886	0.0006	0.5	
Total			30.4	
Light Liquid				0.0071
Leak	65	0.0852	5.5	
Non-Leak	935	0.0017	1.6	
Total			7.1	
Heavy Liquid				0.00023
Leak	4	0.00023	0.00	
Non-Leak	996	0.00023	0.23	
Total			0.23	
Compressor Seals: Gas				0.228
Leak	91	1.608	147	
Non-Leak	909	0.0894	81	
Total			228	
Pressure Relief Valves: Gas				0.104
Leak	36	1.691	61.0	
Non-Leak	964	0.047	43.0	
Total			104.0	

TABLE 2-33. (CONTINUED)

	# Sources[1] Per 1000	Emission[2] Factor (kg/hr)	Emissions per 1000 (kg/hr)	Overall Emission Factor (kg/hr)
Open-Ended Lines: All				0.0017
Leak	39	0.01195	0.47	
Non-Leak	961	0.0015	1.44	
Total			1.91	
Flanges: All				0.00083
Leak	21	0.0375	0.79	
Non-Leak	979	0.00006	0.04	
Total			0.83	

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[1] From SOCMI analysis report (Reference 117): fraction of leaking sources for the 24 unit screening study (Reference 118).

[2] From petroleum refinery emission factor development for fugitive VOC emission sources (Reference 119).

TABLE 2-34. COMPARISON OF EMISSION FACTORS FOR ILLUSTRATIVE SOCMI CASES (ETHYLENE, CUMENE, AND VINYL ACETATE UNITS), AVERAGE SOCMI UNIT, AND PETROLEUM REFINERIES, kg/hr/source

Source	Average SOCMI Unit	Refinery[a]	Ethylene[b]	Cumene[b]	Vinyl Acetate[b]
Pumps - light liquid	0.0494	0.114	0.058*	0.018*	0.002*
- heavy liquid	0.0214	0.021			
Valves - gas	0.0304	0.0268	0.0086*	0.007*	0.0014*
- light liquid	0.0071	0.0109	0.018*	0.006*	0.00023*
- heavy liquid	0.00023	0.00023			
Compressors	0.228	0.636			
Safety/relief valves - gas	0.104	0.16			
Flanges	0.00083	0.00025			
Open-ended lines	0.0017	0.0023			
Sampling connections	0.0150	0.0150			

[a] Source: Reference 120.

[b] Source: Reference 121.

*Emission factors were determined in the SOCMI Analysis report and updated to account for data biasing (see Section 2.2.8).

The average SOCMI unit emission factor for light liquid valves is lower than those for refineries and ethylene units. It is about the same as the light liquid valve emission factor for cumene units, and it is higher than the emission factor for vinyl acetate units. Emission factors for the heavy liquid valves in refineries and average SOCMI units are the same.

The average SOCMI unit emission factor for compressors is lower than the emission factor for refineries, as is the average SOCMI emission factor for safety relief valves. The average SOCMI emission factor for flanges, however, is higher than the one for refineries. The factors for open-ended lines in the average SOCMI unit and in refineries are almost the same. The petroleum refinery emission factor for sampling connections was not modified for application to SOCMI because there is no reason to believe that the amount of sample purge would be different.

The average SOCMI emission factors for light liquid valves and light liquid pumps are verified by comparison with the emission factors determined for the three types of SOCMI units. These average SOCMI factors fall within the range of the emission factors determined in the SOCMI units. However, the average SOCMI emission factor for gas valves does not compare favorably. The average SOCMI emission factor for gas valves is higher than the one determined for gas valves in petroleum refineries and falls outside the range of the emission factors determined in the SOCMI units tested.

Comparisons of the emission factors for light liquid pumps and valves and gas valves from petroleum refineries and the three types of SOCMI units are shown in Figures 2-1, 2-2, and 2-3. As Figure 2-1 shows, the confidence intervals for the SOCMI gas valve emission factors exhibit almost no overlap with the petroleum refinery emission factor confidence interval. And the confidence intervals for the SOCMI gas valve emission factors are narrower than the interval for the petroleum refinery emission factor. This comparative analysis of the statistical measures of confidence indicates that the gas valve emission factors for SOCMI are different from the gas valve emission factor for petroleum refineries. The smaller confidence intervals also suggest that the SOCMI gas valve numbers are better estimators of SOCMI gas valve emissions.

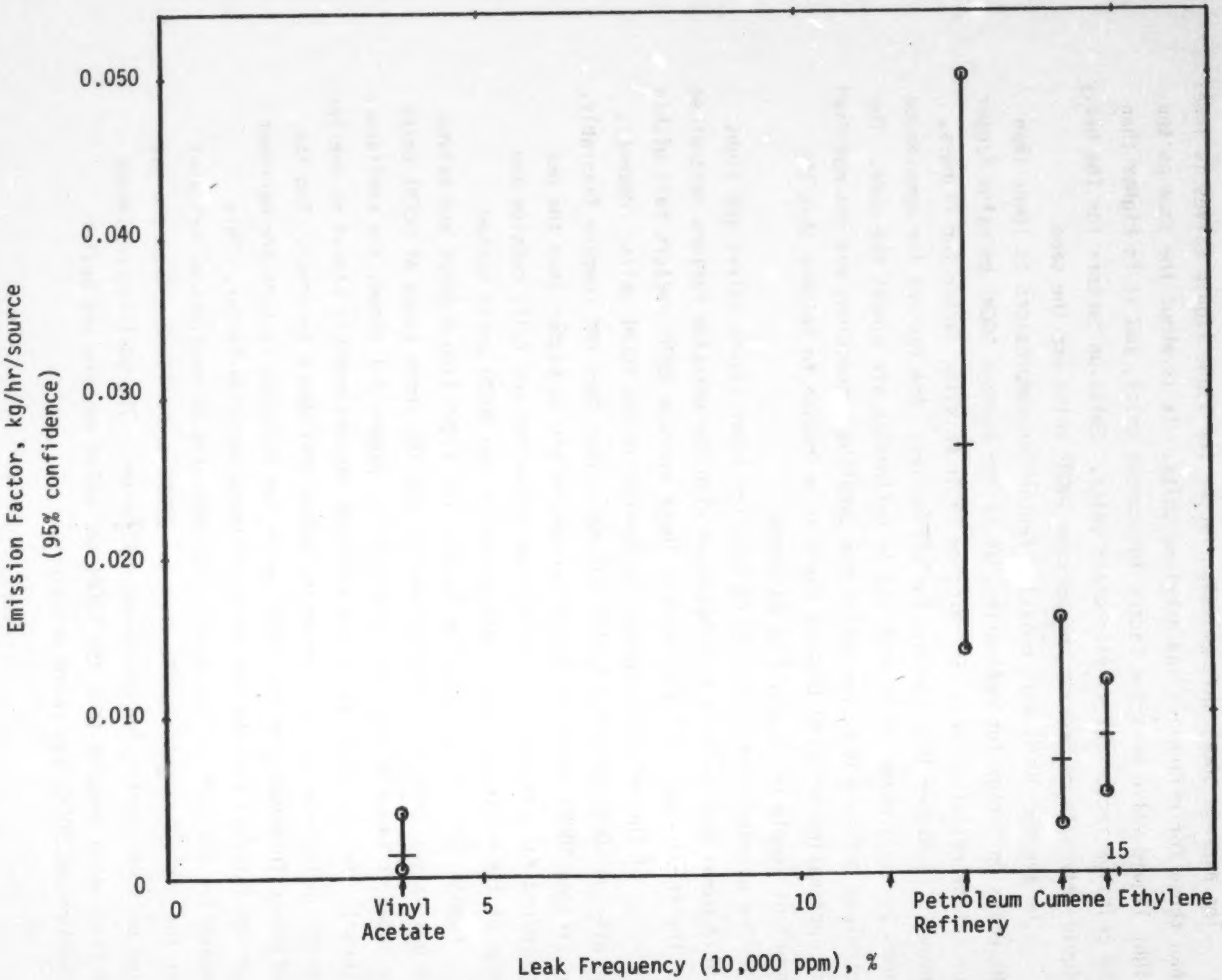


Figure 2-1. Emission factor v. empirical leak frequency: gas valves for petroleum refinery and SOCMI units.

Sources: Reference 122, Reference 123.

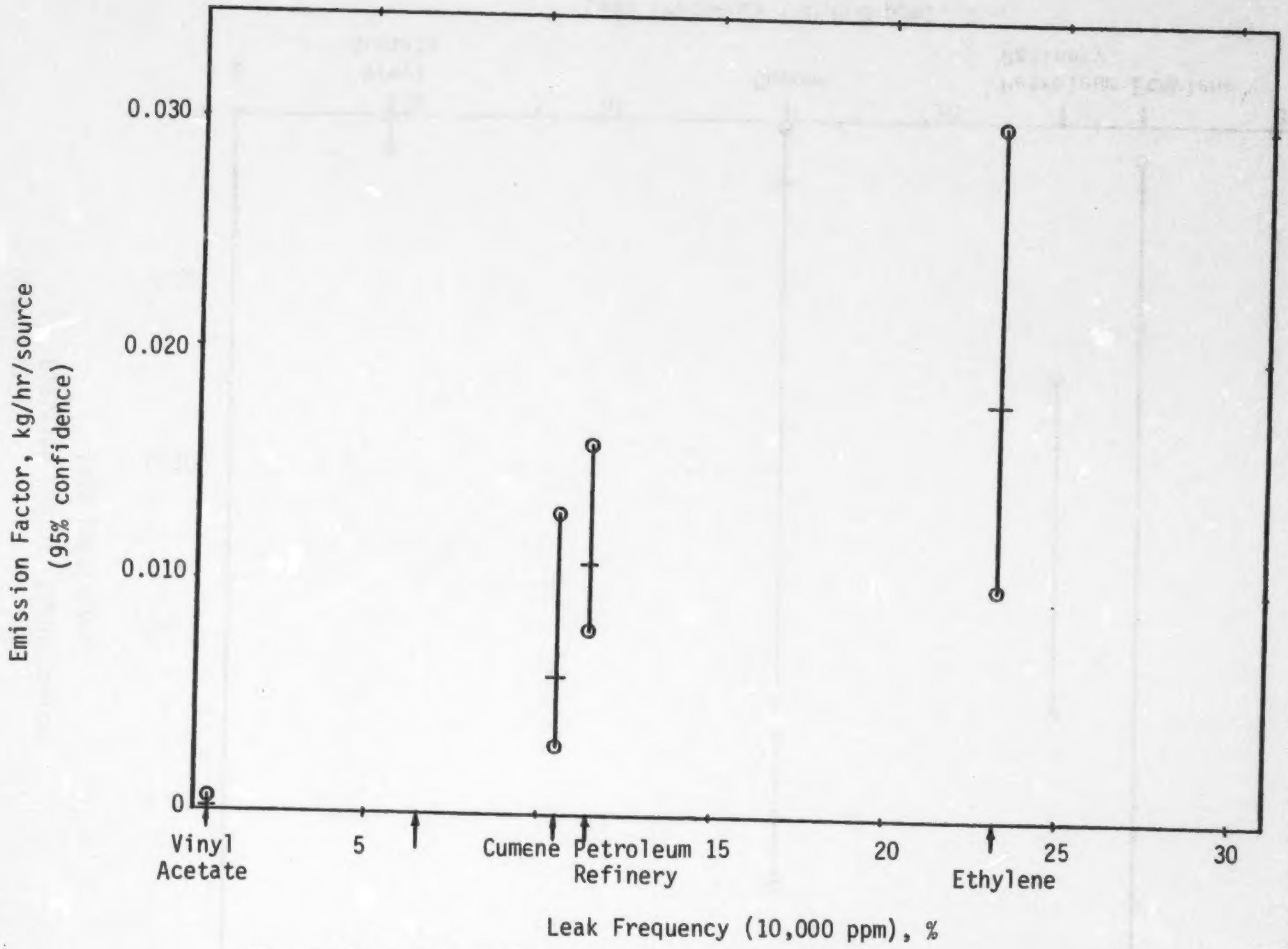
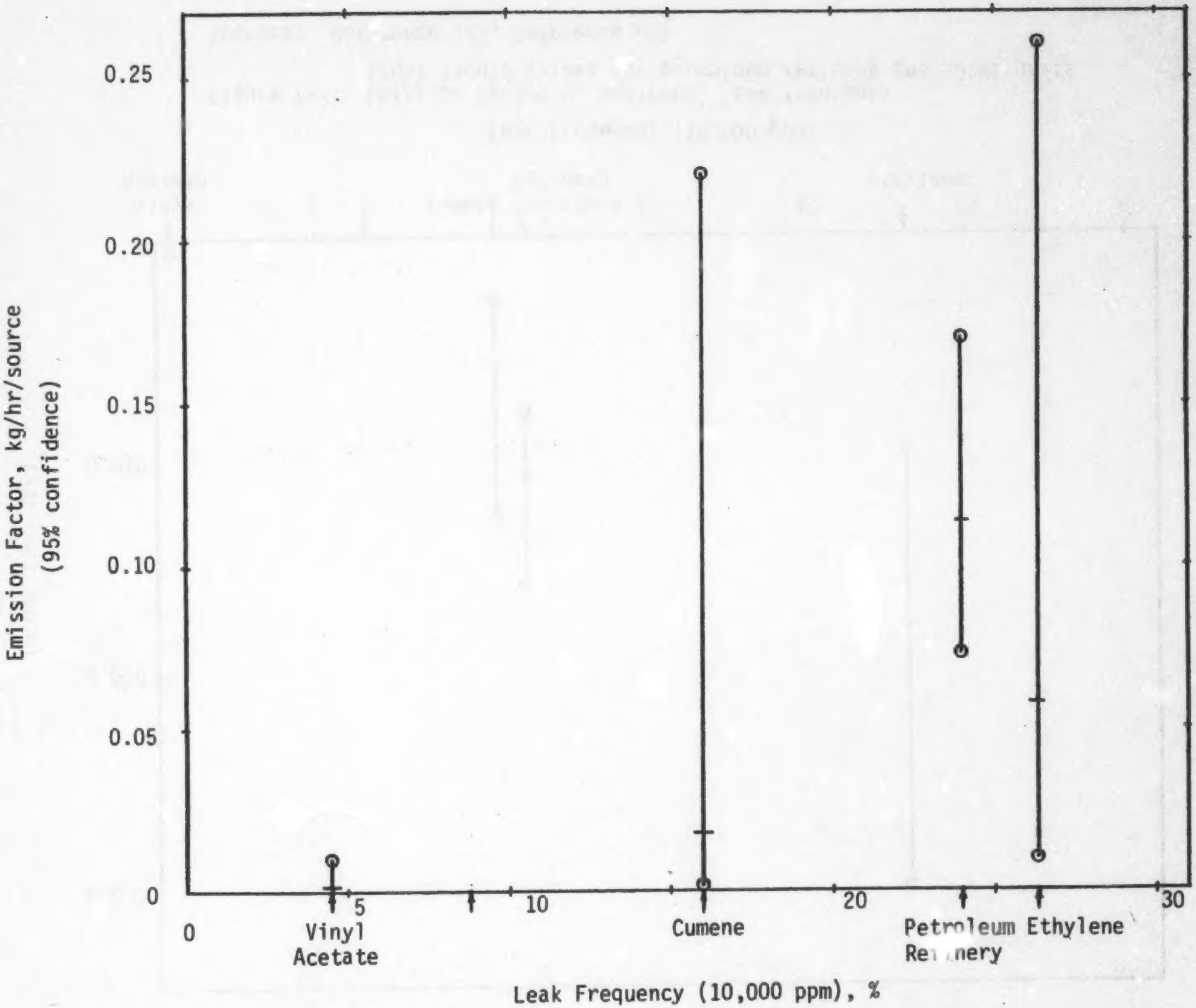


Figure 2-2. Emission factor v. empirical leak frequency: light liquid valves for petroleum refinery and SOCMI units.

Sources: Reference 124, Reference 125.



Factor 2-3. Emission factor v. empirical leak frequency: light liquid pumps for petroleum refinery & SOCMI units.

Sources: Reference 126, Reference 127.

The same comparative analysis for light liquid valves and light liquid pumps (Figures 2-2 and 2-3) does not result in the same conclusions. Substantial overlapping of confidence intervals is seen for petroleum refinery and SOCMI light liquid valves and pumps. This overlap indicates that the emission factors are similar in value within the confidence of the estimates. The SOCMI pump emission factors have very broad confidence intervals, a fact which indicates a small amount of certainty for the value of the emission factor. The petroleum refinery light liquid pump emission factor has a smaller confidence interval and, therefore, is considered a better estimator for light liquid pump emissions.

Based on these considerations, EPA concluded that the gas valve emissions data developed in the SOCMI units are a better basis for estimating gas valve emissions in SOCMI than the data from petroleum refineries. The data further indicate that the petroleum refinery emission factor data for light liquid valves and pumps are the better of the two sets of data for estimating emissions from light liquid valves and pumps.

Therefore, EPA has applied the methodology used to develop SOCMI emission factors from leaking and non-leaking emission factors to the SOCMI gas valve data. The resulting average SOCMI gas valve emission factor is a better estimate of SOCMI gas valve emissions. The final slate of average SOCMI emission factors is shown in Table 2-35.

Assuming these leak/no leak emission factors are applicable to fugitive emission sources in other industries, the overall emission factor for any source of fugitive VOC emissions in any industry can be determined if the leak frequency for the fugitive emission source is known. As shown in the examples in Table 2-36, the emission factors estimated with this technique for gas plants and coke ovens compare favorably with the actual emission factors measured for sources associated with coke ovens and gas plants.

As discussed before, industry commenters also presented SOCMI emission factors[128] based on the leak rates reported in the SOCMI analysis report[129] (see Section 2.3). An apparent decimal point error was corrected in the emission factor for light liquid pump seals. Also, using the methodology presented by the commenters and the revised emission factors determined for

TABLE 2-35. FINAL AVERAGE SOCMI UNIT EMISSION FACTORS

Equipment Component	"Average" SOCMI Factors kg/hr/source
Pump Seals	
Light Liquid	0.0494
Heavy liquid	0.0214
Valves[d]	
Gas	0.0056
Light liquid	0.0071
Heavy liquid	0.00023
Compressor Seals	0.228
Safety relief valves - gas	0.104
Flanges	0.00083
Open-ended lines	0.0017
Sampling connections	0.0150

TABLE 2-36. COMPARISON OF ACTUAL EMISSION FACTORS FOR COKE OVENS AND GAS PLANTS WITH FACTORS ESTIMATED USING THE LEAK/NO LEAK PROCEDURE, kg/hr/source

Source	Coke Ovens[a]		Gas Plants[b]	
	Actual (95% Confidence Interval)	Estimated	Actual (95% Confidence Interval)	Estimated
Pump seals - overall	0.22 (0.054 - 0.75)	0.20[c]	0.063 (0.02 - 0.2)	0.14[c]
Valves - overall	0.015 (0.0014 - 0.14)	0.0066[c] - 0.016[d]	0.020 (0.008 - 0.04)	0.015[c] - 0.044[d]
Compressor seals - gas	0.015 (0.0003 - 0.042)	0.016[e]	0.020 (0.03 - 1.3)	0.89[d]
Flanges	-	0.00006	0.0011 (0.0004, 0.002)	0.0012
Open-ended lines	-	-	0.022 (0.008, 0.04)	0.0027
Pressure relief devices	-	-	0.19 (0.004, 4)	0.33

[a] Source: Reference 130.

[b] Source: Reference 131.

[c] Light liquid service.

[d] Gas service.

[e] Hydrogen service.

SOCMI sources (see Section 2.2.8), another set of emission factors was developed. These are compared in Table 2-37 with those emission factors determined using the leak/no leak emission factors in combination with leak frequencies.

Since industry only presented new factors for light liquid pump seals and vapor and light liquid valves, only those factors are compared here. The methodology employed in generating the industry emission factors involved a weighted average of the factors determined in the SOCMI studies. And, as such, they do not consider the leak rates that were well established during the refinery studies. This procedure resulted in lower estimated emission factors by industry for light liquid pump seals and vapor valves. The industry estimate of emission factor for light liquid valves is higher than the "average" SOCMI factor since it was heavily influenced by the factor determined in ethylene units.

TABLE 2-37. COMPARISON OF EMISSION FACTORS FOR "AVERAGE" SOCMI UNIT TO EMISSION FACTORS SUBMITTED BY INDUSTRY,[a] kg/hr/source

Equipment Component	Industry Emission Factors		"Average" SOCMI Factors
	In Comment[b]	Revised[b]	
Pump Seals			
Light liquid	0.02[c]	0.035	0.0494
Heavy liquid	0.02	0.02	0.0214
Valves[d]			
Gas	0.0065	0.0085	0.0056
Light liquid	0.0045	0.0109	0.0071
Heavy liquid	0.0003	0.0003	0.00023
Compressor Seals	0.441	0.441	0.228
Flanges	0.0003	0.0003	0.00083

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[a] Source: Reference 132.

[b] "In Comment" refers to the values used by industry; "Revised" presents new estimates of emissions factors using industry's methodology and the updated emission factors for SOCMI.

[c] Apparent decimal point error. The number was reported as 0.0045 kg/hr/source. According to the calculation methodology reported, it should have been 0.045 kg/hr/source.

[d] Estimate presented by industry considered a single value for valves ("valves" included in-line valves, safety relief valves, open-ended valves & lines, & sampling connections).

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3. MODEL UNITS

In order to estimate industry wide fugitive emissions of VOC, control costs of emission reduction techniques and environmental impacts for SOCMI units, three model units were developed in the BID. These three model units represented the range of emission source populations that may exist in SOCMI process units. The model units are, therefore, the starting point for projections of industry wide emissions, costs, and environmental impacts associated with various control options. This section presents the basis for the development of the model units in the BID, new information and public comments regarding the model units, and the decisions made by EPA in view of the new information and the comments.

3.1 TECHNICAL BASIS IN THE BID

The model units presented in the BID were used as the basis for the analysis of impacts of the standards. The model units were based primarily on process complexity because fugitive VOC emissions generally are related to the number of equipment components in a process unit, and are not related to equipment size or process unit capacity. The model units used in characterizing fugitive VOC emissions from SOCMI were developed in the study of SOCMI performed for EPA by IT Enviroscience (formerly Hydroscience).[1] Fifty-one process units were surveyed in the Hydroscience study. Based on information from this study and as illustrated in Figures 3-1 and 3-2, there is a general lack of correlation between the number of equipment components (pumps and valves) and the rated production capacity of the process unit. The results of the Hydroscience study and equipment counts provided by engineering design and construction firms are the basis of the model units. In addition, the equipment counts in new units were expected to be comparable to the equipment counts in existing units.

In examining available information on SOCMI units, the most complete information available on equipment counts was found to be the total number

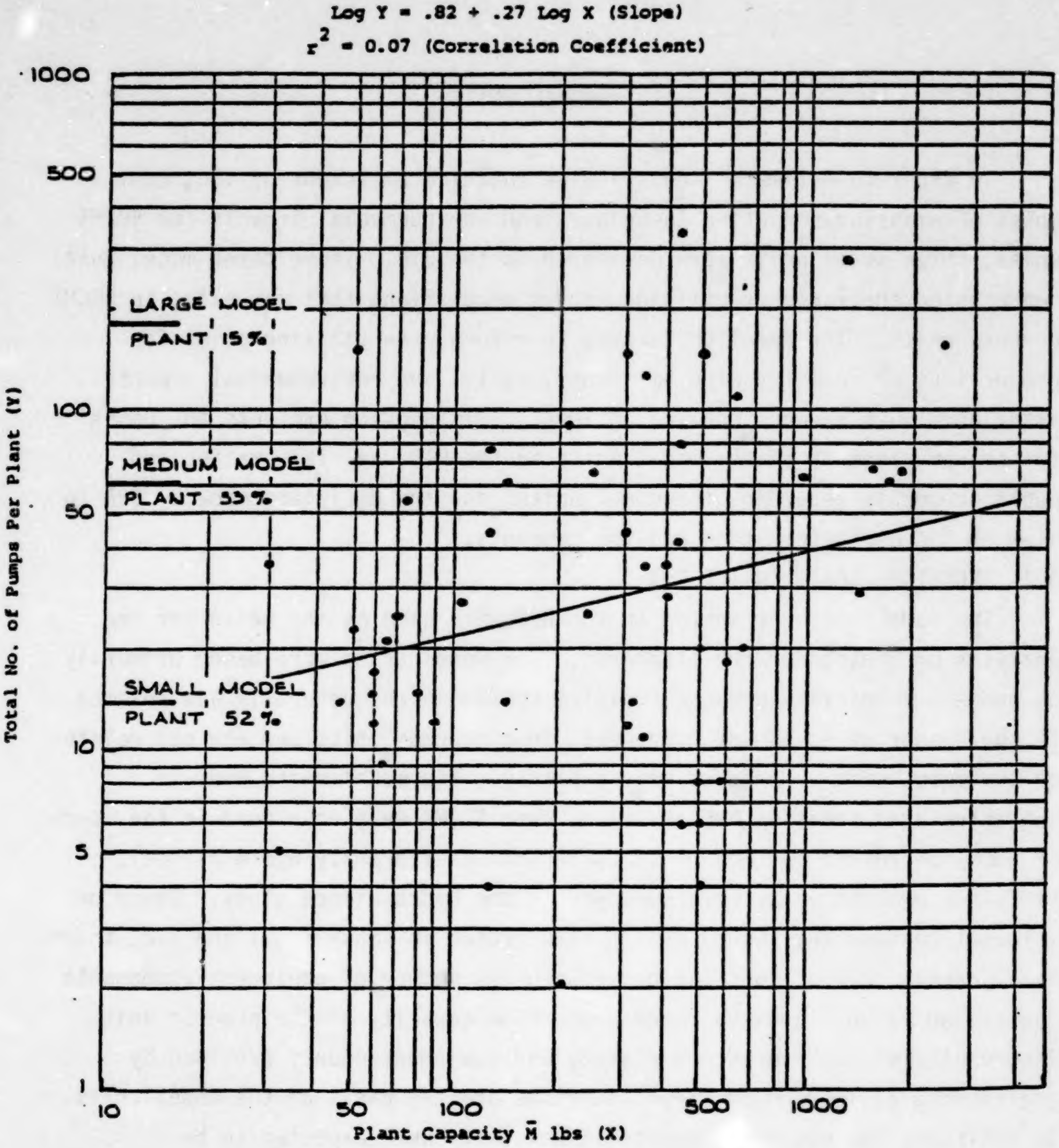

Figure 3-1. Total number of pumps per process unit as a function of the rated annual production capacity (million lbs).[2]

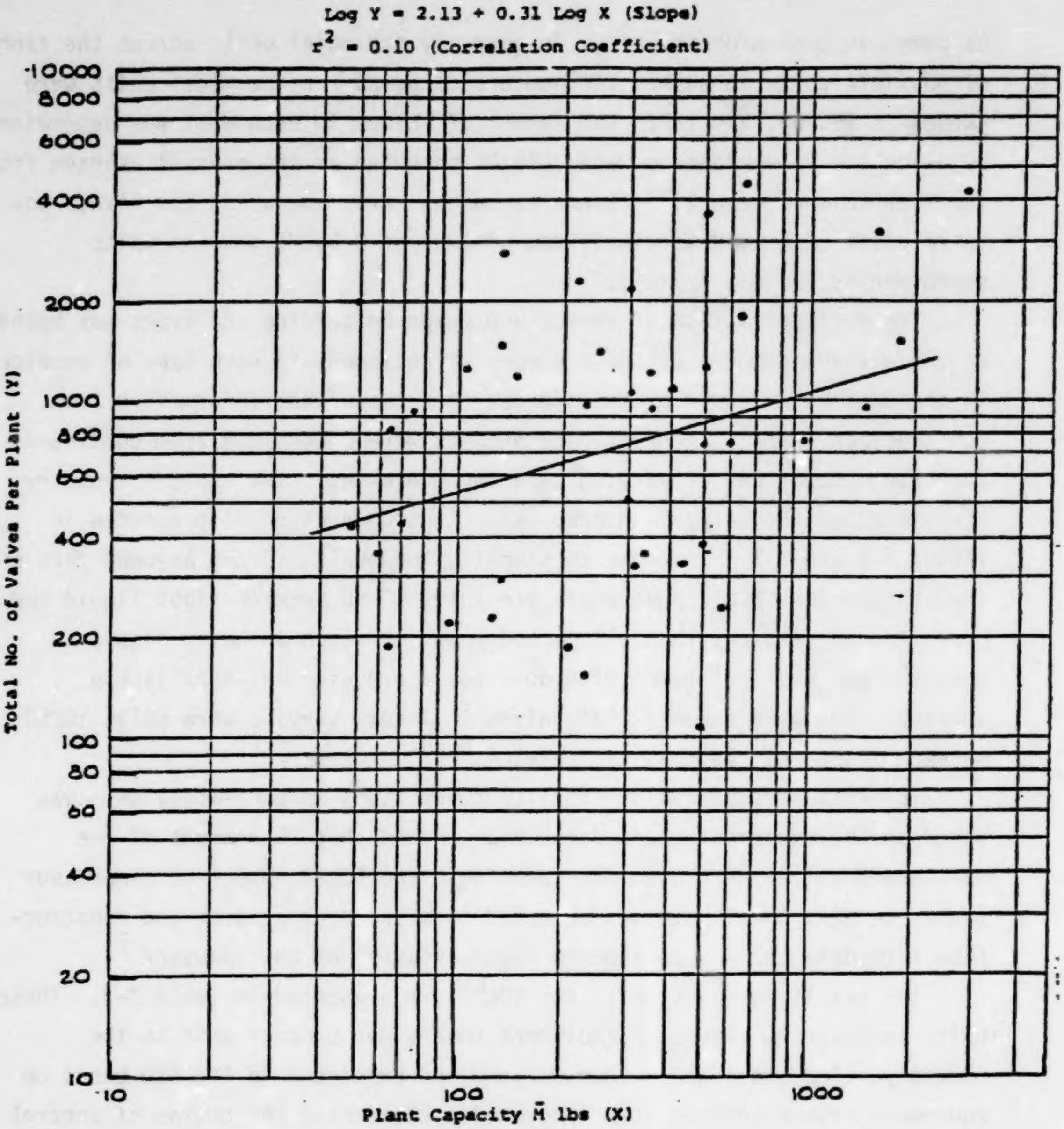

Figure 3-2. Total number of valves per process unit as a function of the rated annual production capacity (million lbs).[3]

of pumps in each process unit. To quantify the model units across the range of possible units in SOCMI, the numbers of pumps for the model units were chosen as 15, 60, and 185. The number of valves in each unit was determined by using the valve-to-pump ratio (25:1) computed as the overall average from the Hydroscience report.[4] Flange estimates were made using the flange-to-valve ratio (1.6:1) determined from a study of 8 SOCMI process units performed by Pullman Kellogg.[5]

The differentiation of valves and pumps by service and types was based on the average numbers of these pieces of equipment in each type of service in the data base formed by the Hydroscience report and information from construction firms. These average numbers were determined from continuous and batch operations of varying capacity processes. The typical industry distributions for valves and pump seals thus generated are presented in Tables 3-1 and 3-2. In order to simplify the analysis, EPA assumed that on the average for SOCMI, pump seals are split 50/50 between light liquid and heavy liquid service, that all packed pumps are used in heavy liquid service, and that all pumps with dual seals are used in light liquid service. EPA also assumed that valves in liquid service were split 50/50 between light and heavy liquid service.[6]

The estimated number of sampling connections in each model unit was based on the equipment count data which showed that 25 percent of the open-ended valves were used for sampling. The total number of compressor seals for each model unit was selected from the Hydroscience and construction firm data and was considered representative of the industry.[7]

The resulting model units for SOCMI are presented in Table 3-3. These units spanned the ranges of equipment counts per process unit in the industry. The model units thus derived and presented in the BID based on equipment counts incorporated information concerning the degree of control currently practiced by industry.

3.2 NEW INFORMATION

Some new information was acquired since the publication of the BID as a result of the 24-unit screening study (previously described in the section on emission factors, Section 2). As seen in Table 3-4, the equipment counts

TABLE 3-1. SOCMI VALVE CHARACTERIZATION[a,b]

Type of Valve	Percent of Total Valves	Percent in Liquid Service	Percent in Vapor (Gas) Service
Safety-relief	3.4	17.0	83.0
Open-ended (sample vent, drain)	27.6	91.0	9.0
In-line (process, control)[c]	69.0	65.0	35.0
All valves	100.0	71.0	29.0

[a] Includes only valves in VOC service.

[b] Reference 8.

[c] Check valves are excluded.

TABLE 3-2. SOCMI PUMP SEAL CHARACTERIZATION[a,b]

Pump Seals	Percent in Use
Mechanical	
Single	71.9
Double	16.7
Packed	10.6
None (sealless)	0.8
Total	100.0

[a] Includes only pump seals in VOC service.

[b] Reference 9.

TABLE 3-3. FUGITIVE EMISSION SOURCES FOR THREE MODEL UNITS[f]

Equipment component[a]	Number of components in model unit[b] Model unit A	Model unit B	Model unit C
Pump seals			
Light liquid service			
Single mechanical	5	19	60
Dual mechanical	3	10	31
Sealless	0	1	1
Heavy liquid service			
Single mechanical	5	24	73
Packed	2	6	20
In-line valves			
Vapor service	90	365	1117
Light liquid service	84	335	1037
Heavy liquid service	84	335	1037
Safety/relief valves			
Vapor service	11	42	130
Light liquid service	1	4	13
Heavy liquid service	1	4	14
Open-ended valves and lines[c]			
Vapor service	9	37	115
Light liquid service	47	189	581
Heavy liquid service	48	189	581
Compressor seals	1	2	8
Sampling connections[d]	26	104	320
Flanges	600	2400	7400
Cooling towers	--[e]	--[e]	--[e]

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[a] Equipment components in VOC service only.

[b] 52% of existing units are similar to Model Unit A.
33% of existing units are similar to Model Unit B.
15% of existing units are similar to Model Unit C.

[c] Sample, drain, purge valves and the associated open end.

[d] Based on 25% of open-ended valves.

[e] Data not available.

[f] Reference 10.

TABLE 3-4. SUMMARY OF SELECTED EQUIPMENT COUNTS FOR MODEL UNITS AND UNITS IN SOCMI 24-UNIT STUDY[a,b]

Unit Number	Process Type	Safety/relief Valves	In-line valves			Open-ended lines			Pumps		Compressors	Flanges
			Gas	Light Liquid	Heavy Liquid	Gas	Light Liquid	Heavy Liquid	Light Liquid	Heavy Liquid		
A	Model unit	11	90	84	84	9	47	48	8	7	1	600
B	Model unit	42	365	335	335	37	189	189	29	30	2	2400
C	Model unit	130	1117	1037	1037	115	581	581	91	93	8	7200
1	Vinyl acetate	31	377	788	67	37	49	8	44	5	4	1940
2	Ethylene	47	2563	1412	1311	56	39	93	22	16	8	5340
3	Vinyl acetate	31	872	1570	61	142	305	15	49	-	4	3820
4	Ethylene	101	2425	2295	54	79	59	3	35	-	3	15980
5	Cumene	10	123	354	71	2	6	-	10	1	-	875
6	Cumene	18	422	573	177	4	10	1	15	2	2	2990
11	Ethylene	65	2396	1118	59	208	144	-	27	-	7	1220
12	Acetone/phenol	29	8	2075	530	2	582	111	90	36	-	2280
20	Ethylene dichloride	30	390	916	-	43	230	-	45	-	-	1020
21	Vinyl chloride monomer	18	93	751	-	4	44	-	10	-	-	980
22	Formaldehyde	3	48	126	-	16	37	-	8	-	-	200
28	Ethylene dichloride	10	168	474	-	27	136	-	22	-	-	280
29	Vinyl chloride monomer	4	420	1806	-	115	470	-	51	-	-	2840
31	Methyl ethyl ketone	1	82	348	-	12	107	-	15	-	-	820
32	Methyl ethyl ketone	2	169	389	-	27	97	-	16	-	1	1140
33	Acetaldehyde	15	236	610	-	51	168	-	32	-	-	880
34	Methylmethacrylate	21	220	1179	-	73	351	-	49	-	-	1425
35	Adipic acid	5	48	17	1232	4	1	200	-	60	-	1175
60	Trichloroethylene/ perchloroethylene	5	52	1800	12	21	483	4	60	-	-	2760
61	1,1,1 - Trichloroethane	-	-	430	-	-	130	-	10	-	-	410
62	Ethylene dichloride	-	29	-	-	22	-	-	-	-	-	45
64	Adipic acid	-	61	-	342	29	-	122	-	33	1	770
65	Acrylonitrile	-	292	723	114	77	202	48	24	10	2	1310
66	Acrylonitrile	-	221	1093	-	68	370	-	42	-	-	1935

[a] Reference 11.
[b] Reference 12.

for the 24 process units in the screening study generally fall within the range of equipment counts described by the model units presented at proposal. For example, safety relief valves ranged from none to 101 per process unit, light liquid pumps ranged from none to 90 and compressors ranged from none to 8. Ethylene units are the exception with a high number of valves and flanges.

The degree of control existing in SOCMI for compressors was indicated to be higher than assumed in the BID. It was found from the 24 unit study that the seal areas of 60 percent of the compressors were shrouded and vented either back to the process or to a flare header.[13] This high degree of control resulted in a low leak frequency measured for compressors. At this time, EPA is gathering more information concerning the existing level of control for pumps in SOCMI. Details about the pumps and barrier fluid systems in the SOCMI units tested are being requested.

3.3 PUBLIC COMMENT

Few comments were received from the public concerning the model units presented at proposal. The comments received from industry centered around four major points.

1. The emission factor for open-ended lines in the BID included two components: one for leakage through the valve seat ("the open end") and one for leakage around the valve stem (or valve leakage). This distribution of emissions was found to be confusing to several commenters.

2. Specific comments were also received on the degree of control practiced in the industry. Commenters stated that open-ended lines in process units built today use plugs, caps, and blinds. And 75 percent of the sampling connections used today are of the closed purge variety.[14]

3. One commenter presented the premise that there is a relationship between fugitive emissions and plant size or production rate. For example, smaller capacity units leak less on a mass basis than larger capacity units.

4. Another commenter stated that the model units should not be presented as small, medium, and large units. Rather, the model units should be classified as low-leak, high-leak, and ethylene type units as was done in the SOCMI analysis report.

3.4 EPA's CONCLUSIONS

After reviewing the data bases and comments received on the model units, EPA decided to retain the model units presented in the BID for purposes of analysis. But, given some of the comments and new information concerning the degree of control presently practiced by the industry, some clarifications and adjustments have been made. A comparison of the old and new model units is presented in Table 3-5.

First, to avoid the confusion concerning the emission factor for open-ended lines, the emission factor was changed to represent only the emissions through the valve seat ("the open end"). The valve counts were then adjusted to include those valves that were previously included as part of the open-ended line. Also, since only one emission factor for open-ended lines in all VOC services (gas, light liquid, heavy liquid) was used, a single equipment count was used for all open-ended lines instead of individual counts for gas, light liquid, and heavy liquid services. In addition, nearly all open-ended lines have been assumed to be currently controlled since industry had stated that capping and plugging open-ended lines is standard industry practice.

Second, the number of uncontrolled sampling connections represented in the model units was reduced by 75 percent. EPA decided to make this change because industry commented that 75 percent of the sampling connections in the existing process units currently use closed purge sampling mechanisms.

Third, the number of compressor seals was not adjusted to reflect the higher degree of control indicated by the 24-unit screening study. Instead, the emission factor for compressors accounted for the level of control. The degree of control for compressors was indicated by the low leak frequency determined for compressors in the 24-unit study. The leak frequency reported for the 24-unit study was based on all compressors, controlled as well as uncontrolled. And the emission factor generated for compressors consisted of the emissions due to all leaking compressors as well as the emissions due to all non-leaking compressors (including controlled compressors). Therefore, the fugitive emissions due to compressors must be estimated based on all compressors, not just uncontrolled compressors.

TABLE 3-5. EQUIPMENT COUNTS FOR FUGITIVE VOC EMISSION SOURCES IN SOCMI MODEL UNITS

	Equipment Counts[b]					
	BID Analysis			Revised Analysis		
Equipment Component[a]	Model Unit A	Model Unit B	Model Unit C	Model Unit A	Model Unit B	Model Unit C
Pump Seals						
Light Liquid Service						
Single mechanical	5	19	60	5	19	60
Dual mechanical	3	10	31	3	10	31
Sealless	0	1	1	0	1	1
Heavy Liquid Service						
Single mechanical	5	24	73	5	24	73
Packed	2	6	20	2	6	20
Valves						
Vapor service	90	365	1117	99	402	1232
Light liquid service	84	335	1037	131	524	1618
Heavy liquid service	84	335	1037	132	524	1618
Safety/relief valves						
Vapor service	11	42	130	11[c]	42[c]	130[c]
Light liquid service	1	4	13	1	4	13
Heavy liquid service	1	4	14	1	4	14
Open-ended lines				104[d]	415[d]	1277[d]
Vapor service	9	37	115			
Light liquid service	47	189	581			
Heavy liquid service	48	189	581			
Compressor seals	1	2	8	1	2	8
Sampling connections	26	104	320	26[e]	104[e]	320[e]
Flanges	600	2400	7400	600	2400	7400

[a] Equipment components in VOC service only.

[b] 52% of existing units are similar to Model Unit A.
33% of existing units are similar to Model Unit B.
15% of existing units are similar to Model Unit C.

[c] Seventy-five percent of gas safety/relief valves are assumed to be controlled at baseline; therefore the emissions estimates are based on the following counts: A,3; B,11; C,33.

[d] All open-ended lines are considered together with a single emission factor; 100% controlled at baseline.

[e] Seventy-five percent of sampling connections are assumed to be controlled at baseline, therefore, the emissions estimates are based on the following counts: A,7; B,26; C,80.

However, the compressors that are already controlled need not be considered for the purpose of the cost analysis. That is, since 60 percent of all compressors are controlled, the cost of control due to regulation is applicable only to 40 percent of the compressors in the model unit. This gives 0.4, 0.8, and 3.2 compressors for cost analysis in model units A, B, and C respectively rather than 1, 2, and 8 compressors for the environmental analysis.

Next, the number of uncontrolled safety relief valves was reduced to 25 percent. The degree of control found in the 24-unit screening study was higher than that reflected in the model units. Some units had nearly all safety relief valves tied into flares. Based on this information, it is expected that at least half of the safety relief valves will be controlled. Therefore, the assumption was made that 75 percent of safety relief valves in new, modified, or reconstructed SOCMI units will be controlled.

The model units were not changed to reflect a relationship between fugitive emissions and production rate. There are no data relating fugitive emissions to throughput or production rate. Instead, data collected in the refinery and SOCMI studies indicate that process fluid vapor pressure is the primary factor influencing the fugitive emissions rate. Furthermore, data indicate[15] that there is no relationship between number of fugitive emission sources and throughput. Therefore, EPA judged that fugitive emissions varied with the number of components in a process unit (i.e., complexity) and not with the production rate of the process unit.

And finally, based on the results of the SOCMI and petroleum refining screening and maintenance studies, leak frequency might have been used as a supplementary basis for considering model units as suggested by one commenter. However, several complications make it impracticable to do so. For example, there is no information available on the breakdown of the number of process units in each of the three leak frequency categories. It is also impracticable to do a cost analysis for model units that are based on leak frequencies. Without any of this information, industry wide impacts cannot be estimated. In addition, it is not practicable to categorize a given process type as low, high, or ethylene type. For instance, one methyl

ethyl ketone (MEK) unit in the 24 unit study was a low leak unit. Another MEK unit fell in the high leak category. Some units may have low leak frequency for one type of fugitive emission source (e.g. valves) and a high leak frequency for another type of emission source (e.g. pumps). These leak frequencies may also change over time. Therefore, EPA concluded that leak frequencies should not be the basis for the model units. However, EPA plans to evaluate leak frequencies on a fugitive emission source basis in determining whether alternative control strategies should be selected for fugitive emission sources with low leak frequencies.

3.5 REFERENCES

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2. Reference 1, p. B-4.

3. Reference 1, p. B-5.

4. Reference 1, p. II-13.

5. Pullman Kellogg. Equipment Component Analysis for Identification of Potential Fugitive Emission Sources. (Prepared for U.S. Environmental Protection Agency.) Held on file at Emission Standards and Engineering Division. Research Triangle Park, N.C. June 1978.

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7. Reference 1, p. II-13.

8. Reference 1, p. II-10.

9. Reference 1, p. II-10.

10. Reference 1, p. II-12.

11. Reference 1, p. II-12.

12. Blacksmith, J.R., G.E. Harris, and G.L. Langley. (Radian Corporation.) Frequency of Leak Occurrence for Fittings in Synthetic Organic Chemical Plant Process Units. (Prepared for U.S. Environmental Protection Agency.) Washington, D.C. EPA Publication No. EPA-600/2-81-003. September 1980.

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14. Memo from Dimmick, F., EPA:SDB, to Wyatt, S., EPA:SDB. September 4, 1980. 10p. Notes of meeting with Texas Chemical Council on July 18, 1980.

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4. EMISSION REDUCTIONS

Estimates of the effectiveness of control techniques for fugitive emissions of VOC from SOCMI sources were presented in the BID (EPA-450/3-80-033a).[1] Some new information has become available concerning the effectiveness of the control techniques presented in the BID. Some of this information allows more accurate estimation of emission reductions which can be achieved through the use of these control techniques. This section contains a discussion of emission reductions achievable in light of the basis presented in the BID and that new information. The discussion is arranged by fugitive emission source: valves, pumps, sampling systems, safety relief valves, open-ended lines, compressors, and control devices. For each of these fugitive emission sources the basis presented in the BID is reviewed, new information is presented, and relevant public comments are summarized. Finally, EPA's view of the effectiveness of controls and how that effectiveness should be estimated is presented.

4.1 VALVES

4.1.1 Technical Basis Presented in the BID

The BID (EPA-450/3-80-033a) included a discussion of fugitive emissions from valves and the control techniques for reduction of those emissions. Two general control techniques were considered in the BID: a leak detection and repair program and leakless equipment.

Leakless equipment for valves, such as diaphragm and bellows seal valves, eliminate the seals which allow fugitive emissions and, thus, their control effectiveness is virtually 100 percent. However, as noted in the BID, the applicability of these types of valves is limited. Because these leakless types of equipment are limited in their applicability, the regulatory alternatives developed in the BID only incorporated leak detection and repair programs. The leak detection methods considered were individual component surveys (with soap and instruments), area surveys, and fixed point monitors.

The leak detection method selected for incorporation in the regulatory alternatives was individual component surveys using a portable VOC instrument. The individual component survey was selected because it was more reliable in detecting leaks than fixed area monitors or walk-through surveys. The portable VOC monitor was selected over the other semi-quantitative method of leak detection, application of soap solutions because the temperature of the fugitive emission source, the physical configuration, and the relative movement of parts often interfere with bubble formation.

Repair procedures for valves were also presented in the BID. The basic repair procedure for leaking valves is the tightening of the packing gland. Depending on site specific factors, it may be possible to repair valves by injection of a sealing fluid into the source. In some cases it would be necessary to replace the packing or to replace the valve.

Data from five studies on the effects of maintenance on fugitive emissions from valves were presented in the BID. These studies are briefly described below.

Union Oil Maintenance Study[2] -- The Union Oil valve maintenance study consisted of performing undirected maintenance on valves selected from 12 different process units. Maintenance procedures in this study consisted of adjusting the packing gland while the valve was in service. Undirected maintenance consists of performing valve repairs without simultaneous measurement of the VOC concentration detected. Directed maintenance involves simultaneous measurement during the repair procedure. With directed maintenance repair procedures are continued until the VOC concentration detected drops to a specified level or further reduction in the emission level is not possible. Also, maintenance may be curtailed if increasing VOC concentrations result.

The Union Oil data were obtained with a Century Systems Corporation Organic Vapor Analyzer, OVA-108, calibrated with methane. All measurements were taken at a distance of 1 cm from the seal. Correlations developed in a study of six refineries in the Bay Area[3] were used to convert the data from

OVA readings taken at one centimeter to readings equivalent to those measured with a Bacharach TLV (calibrated to hexane) at the leak interface (TLV-0). Two sets of results were provided; the first includes all repaired valves with before maintenance screening values greater than or equal to 5,300 ppmv (OVA-108), and the second includes valves with before maintenance screening values below 5,300 ppmv (OVA-108).[a] Estimates of emissions were made using correlations of emissions with screening values developed by EPA in the Petroleum Refinery Study.[4]

The results of the Union Oil data are shown in Table 4-1. The results of this study indicated that maintenance on valves with initial screening values above 10,000 ppmv (OVA-108) is much more effective than maintenance on valves leaking at lower rates. In fact, in this study 124 out of 133 valves originally screening over 5300 ppm had lower screening values after maintenance while only 13 out of 21 valves originally screening under 5300 ppm had lower screening values after maintenance.

Shell Maintenance Study[5] -- The Shell maintenance program consisted of two parts. First, valve repairs were performed on 171 leaking valves. In the second part of the program, 162 of these valves were rechecked and additional maintenance was performed. Maintenance consisted of adjusting the packing gland while the valve was in service. The second part of the program was conducted approximately one month after the initial maintenance period. The information reported by Shell did not indicate whether the maintenance procedures were directed or undirected.

VOC emissions were measured using the OVA-108 calibrated with methane and readings were obtained one centimeter from the source. These data were

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[a] A screening value of 5,300 ppmv, obtained with an OVA at 1cm from the leak interface, is equivalent to a screening value of 10,000 ppmv measured directly at the leak interface by a Bacharach Instrument Co. "TLV Sniffer" calibrated with hexane. The OVA-1cm readings were converted to equivalent TLV-0cm readings from the following reasons:
(1) EPA correlations which estimate leak rates from screening values were developed from TLV-0cm data.
(2) Additional maintenance study data existed in the TVL-0cm format.
(3) Method 21 specifies 0cm screening procedures.

TABLE 4-1. SUMMARY OF MAINTENANCE STUDY RESULTS FROM THE UNION OIL CO. REFINERY IN RODEO, CALIFORNIA

	All valves with initial screening values >5300 ppmv[a]	All valves with initial screening values >5300 ppmv
Number of repairs attempted	133	21
Estimated emissions before maintenance, kg/hr	9.72	0.323
Estimated emissions after maintenance, kg/hr	4.69	0.422
Number of successful repairs (<5300 ppmv after maintenance)	67	--
Number of valves with decreased emissions	124	13
Number of valves with increased emissions	9	8
Percent reduction in emissions	51.8	-30.5
Percent successful repairs	50.4	--
Percent of valves with decreased emissions	90.2	61.9
Percent of valves with increased emissions	6.8	38.1

[a] The value 5300 ppmv, taken with the OVA-108 at 1 cm., generally corresponds to a value of 10,000 ppmv taken with a "TLV Sniffer" at 0 cm.

Source: Reference 6.

transformed to TLV-0 cm (calibrated to hexane) values as were the Union data. And, the same methods of data analysis used in the Union Oil study were applied to the Shell data. Emission rates were generated by using correlations of emission rates and screening values generated by EPA in the Petroleum Refinery Study.[7]

The results of the Shell maintenance study are given in Table 4-2. The results show that all of the valves with screening values above 5300 ppmv had lower screening values after maintenance in March. The results for successive maintenance attempts in April show that 151 out of 152 valves had decreased screening values after maintenance.

EPA Refinery Maintenance Study[8] -- Repair data were collected on valves located in four refineries. The effects of both directed and undirected maintenance were evaluated. Maintenance consisted of routine operations, such as tightening the packing gland or adding grease. Other data, including valve size and type and the processes' fluid characteristics, were obtained. Screening data were obtained with the Bacharach Instrument Company's "TLV Sniffer" calibrated to hexane and readings were taken as close to the source as possible.

Unlike the Shell and Union studies, emission rates were not based on the screening value correlations. Rather, each valve was sampled to determine emission rates before and after maintenance. These values were used to evaluate emissions reduction.

The results of this study are given in Table 4-3. Of interest here is a comparison of the emissions reduction for directed and undirected maintenance. The results indicate that directed maintenance is more effective in reducing emissions than is undirected maintenance, particularly for valves with lower initial leak rates. While for most of the valves tested, the emission reductions achieved were greater than 80 percent, the results showed an increase in total emissions of 32.6 percent for valves with initial screening values less than 10,000 ppmv which were subjected to undirected maintenance. However, this increase is due to a large increase in the emission rate of only one valve.

TABLE 4-2. SUMMARY OF MAINTENANCE STUDY RESULTS FROM THE SHELL OIL COMPANY REFINERY IN MARTINEZ, CALIFORNIA

	March maintenance		April maintenance	
	All repaired valves with initial screening values ≥ 5300 ppmv[a]	All repaired valves with initial screening values <5300 ppmv	All repaired valves with initial (March) screening values ≥ 5300 ppmv	All repaired valves with initial (March) screening $<$values 5300 ppmv
Number of repairs attempted	161	11	152[c]	11[d]
Estimated emissions before maintenance, kg/hr[b]	11.08	0.159	2.95	0.060
Estimated emissions after maintenance, kg/hr[b]	2.66	0.0	0.421	0.0
Number of successful repairs (<5300 ppmv after maintenance)	105	--	45	--
Number of valves with decreased emissions	161	11	151	11
Number of valves with increased emissions	0	0	1	0
Percent reduction in emissions	76.0	100.0	85.7	100.0
Percent successful repairs	65.2	--	83.3	--
Percent of valves with decreased emissions	100.0	100.0	99.3	100.0
Percent of valves with increased emissions	0.0	0.0	0.7	0.0

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[a] The value 5300 ppmv, taken with the OVA-108 at 1 cm., generally corresponds to a value of 10,000 ppmv taken with a "TLV Sniffer" at 0 cm.

[b] Shell reported the screening value of all valves which measured <3000 ppmv (<1500 ppmv-TLV at 0 cm.) as non-leakers. Emissions estimates obtained from emission factors.

[c] Initial value of 90 of these valves was <1500 ppmv-TLV at 0 cm., 54 valves screened ≥ 5300 (note nine valves from initial data set not rechecked in April).

[d] Initial value of 10 of these valves was <1500 ppmv-TLV at 0 cm.

Source: Reference 9.

TABLE 4-3. SUMMARY OF EPA REFINERY MAINTENANCE STUDY RESULTS

	Repaired valves with initial screening values $\geq$10,000 ppmv		Repaired valves with initiall screening values <10,000 ppmv	
	Directed Maintenance	Undirected Maintenance	Directed Maintenance	Undirected Maintenance
Number of valves repaired	9	23	10	16
Measured emissions before maintenance kg/hr	0.107	1.809	0.0332	0.120
Measured emissions after maintenance kg/hr	0.0139	0.318	0.0049	0.159
Number of successful repairs (<10,000 ppmv after maintenance)	8	13	-	-
Number of valves with decreased emissions	9	21	6	15
Number of valves with increased emissions	0	2	4	1
Percent reduction in emissions	87.0	82.4	85.2	-32.6
Percent successful repairs	88.9	56.5	-	-
Percent of valves with decreased emissions	100.0	91.3	60.0	93.8
Percent of valves with increased emissions	0.0	8.7	40.0	6.3

Source: Reference 10.

Unit D (Ethylene Unit) Maintenance Study[11] -- Maintenance was performed by Unit D personnel. VOC concentration measurements were made using the OVA-108 calibrated with methane, and readings were obtained as close as possible to the source. The results of this study are shown in Table 4-4. Directed and undirected maintenance procedures were used. The results show that follow up directed maintenance on valves not repaired by undirected maintenance results in more repairs being successfully completed than when undirected maintenance is used alone.

Chevron Refinery Study[12] -- The Chevron study included inspection of 33,000 valves. A Century OVA-108 hydrocarbon analyzer was used and the VOC concentration was measured at 1 cm from the source. Approximately 4 percent of the screened valves were found leaking. Maintenance consisted of adjustment of the packing. Following this maintenance procedure, 93 percent of the leakers were repaired. Approximately 5 percent of the leakers required repacking. Less than 1 percent required a more elaborate repair procedure such as injecting a sealant type material. Similarly, less than 1 percent of the leakers required replacement.

Summary of Studies -- The following conclusions were drawn from the five maintenance studies presented in the BID:

1. A reduction in emissions may be obtained by performing maintenance on valves with screening values above 10,000 ppm (measured at the source).
2. The reduction in emissions due to maintenance of valves with screening values below 10,000 ppm is not as dramatic and may result in increased emissions if undirected maintenance is used.
3. Directed maintenance is preferable to undirected maintenance for valve repair.

Based on the results of these five studies and other factors, four regulatory alternatives were constructed which incorporated leak detection and repair programs. The regulatory alternatives constructed for valves presented in the BID were as follows:

TABLE 4-4. MAINTENANCE EFFECTIVENESS UNIT D ETHYLENE UNIT BLOCK VALVES

UNDIRECTED MAINTENANCE		
1. Total number subjected to repair attempts	37	
2. Successful repairs (VOC <10,000 ppm)	22	
% Repaired		59%
Followup DIRECTED MAINTENANCE		
3. Number of valves unrepaired by undirected maintenance subjected to directed maintenance	14	
4. Number repaired by followup directed maintenance	5	
% of unsuccessful repaired by directed maintenance		36%
UNDIRECTED AND DIRECTED MAINTENANCE		
5. Total number repaired based on undirected maintenance and follow-up directed maintenance	27	
% Repaired		73%

Source: Reference 13.

1. Regulatory Alternative I: No requirements
2. Regulatory Alternative II: Quarterly monitoring and repair of all gas valves and annual monitoring and repair of light liquid valves.
3. Regulatory Alternative III: Monthly monitoring and repair of all valves.
4. Regulatory Alternative IV: Same as regulatory alternative III.

The emission reductions from valves due to leak detection and repair programs were calculated using the ABCD model presented in Chapter 4 of the BID in the following manner.

Reduction efficiency = A x B x C x D

where:

A = Theoretical maximum control efficiency = fraction of total mass emissions for the source with VOC concentrations greater than the action level.

B = Leak occurrence and recurrence correction factor = correction factor to account for sources which start to leak between inspections (occurrence); for sources which are found to be leaking, are repaired and start to leak again before the next inspection (recurrence); and for known leaks which are not repaired.

C = Non-instantaneous repair correction factor = correction factor to account for emissions which occur between detection of a leak and subsequent repairs; that is, repair is not instantaneous.

D = Imperfect repair correction factor = correction factor to account for the fact that some sources which are repaired are not reduced to zero emission levels.

The correction factors can, in turn, be determined from the following expressions:

$$(1) \quad B = 1 - \frac{\overline{n}_m}{N}$$

(2) $C = \frac{365 - t}{365}$

(3) $D = 1 - \frac{f}{F}$

where:

$\overline{n}_m$ = Average number of leaks occurring and recurring over the monitoring interval (including known leaks which were not repaired).

N = Total number of sources at or above the action level.

t = Average time before repairs are made.

f = Average emissions for repaired sources.

F = Average emission factor for all sources at or above the action level.

The inputs to the model were selected based on a combination of the conclusions from the five maintenance studies and engineering judgement. The following are the inputs and the rationale behind their selection.

A factor: The theoretical maximum control efficiency depends on the action level. An action level of 10,000 ppm was chosen for two main reasons: (1) the monitoring instrument is designed for measuring a maximum concentration of 10,000 ppm without the use of a dilution probe and (2) based on refinery data, a large proportion of mass emissions is from valves at 10,000 ppm or greater (i.e., 98 percent for light liquid valves and 84 percent for gas valves).

B factor: Since quantitative data were not available, the leak occurrence and recurrence correction factor was chosen based on engineering judgement. It was estimated that 10 percent of initially leaking sources will occur, recur, and remain leaking between monthly monitoring intervals (i.e., $n_m = 0.1$ N). Therefore, the average number of occurring, recurring, and remaining leaks between monitoring intervals was $\overline{n}_m = 0.05N$; so $B = 1 - \frac{0.05N}{N} = 0.95$ for monthly monitoring.

C factor: The regulatory alternatives in the BID considered a 15-day time limit for the repair of leaking valves. Some valves were expected to be repaired immediately, while some were expected to take as long as 15 days. On the average, it was expected that leaks would be repaired in 7.5 days (i.e., $t = 7.5$), so $C = \frac{365-7.5}{365} = 0.98$.

D factor: All sources which were repaired were assumed to be reduced to a 1000 ppm concentration level. Results from the petroleum refinery study of fugitive emissions showed that the average emission factor at 1000 ppm(f) was estimated to be 0.001 kg/hr (gas valves) and 0.004 kg/hr (light liquid valves). From the same study the average emission factor at $\geq$10,000 ppm(F) was 0.21 kg/hr (gas valves) and 0.07 kg/hr (light liquid valves). Therefore, $D = 1 - \frac{f}{F}$ was computed to be 0.99 for gas valves and 0.94 for light liquid valves.

Based on the above inputs to the model, the control efficiency (AxBxCxD) of a monthly leak detection repair proposed (Regulatory Alternatives III and IV) for valves were calculated to be 0.90 for gas valves and 0.74 for light liquid valves. The control efficiency for Regulatory Alternative II (quarterly monitoring for gas valves and annual monitoring for light liquid valves) was calculated to be 0.86 for gas valves and 0.62 for light liquid valves.

4.1.2 New Information

Results from three new studies became available after proposal. Also, an improved model was developed for calculating emissions and emission reductions for fugitive emission sources operating under a leak detection and repair program. This information developed since proposal is summarized below.

Maintenance Study[14] -- Effectiveness of maintenance on reducing fugitive emissions from valves in six process units was evaluated in this study. The methodology employed to generate the technical results of the study is presented in the section on Emission Factors. The results of the study relevant to emissions reduction include the determination of occurrence rate recurrence rate, overall emission reduction, and percent successful repair. These results are summarized in Table 4-5.

The successful repair rate determined in this study was 29 percent. However, the emission reduction achieved by reducing the screening values of 29 percent of the valves from $\geq$10,000 ppm to <10,000 ppm was 71.3 percent. These figures indicate that attempting maintenance, even if it is unsuccessful in terms of screening value, reduces emissions significantly.

Analysis Report[15] -- As indicated in the Emission Factor Section, the results of the Maintenance Study[16] and the twenty-four unit study[17] were combined for more in-depth analysis. Estimates of emission reductions due to LDRPs from successful and unsuccessful repair and mass emissions from valves screening $\geq$10,000 ppm were made. These estimates are shown in Table 4-6.

An Analysis of Allied HDPE Study Data[18] -- The details of this study are described in the emission factors section. This study was performed over a period of 10 months in Allied's newest existing high density polyethylene unit (HDPE). The fugitive emissions data collected by Allied was analyzed for EPA by PEDCo. The study consisted of six screening and emissions measurement tests performed on valves and flanges. The relevant portions of this study are summarized in Table 4-7. The results of this study showed a high rate of successful repair (over 80 percent). The numbers also indicated a 30-day recurrence rate of 7.8 to 11.1 percent which was higher than the 30-day occurrence rate of 3.6 to 7.4 percent.

There are some additional considerations that must be made when examining these results. The schedule for the series of six tests is shown in Figure 4-1. As can be noted in Figure 4-1, there are some inconsistencies in the repair effectiveness measures that were determined. For example, valves were not rescreened immediately after maintenance in Test 1; therefore, immediate leak recurrence is included in the Test 1 estimate of repair effectiveness. And rescreening for Test 5 followed the maintenance by a month. This means that the repair effectiveness for Test 5 includes both immediate recurrence and long-term recurrence. As seen in Figure 4-1, rescreening in the remaining tests closely followed maintenance efforts,

TABLE 4-5. SUMMARY OF MAINTENANCE STUDY RESULTS

	Ethylene Units	Cumene Units	Vinyl Acetate Units	All Units
30-day Occurrence rate, (% of non-leaking valves)	2.0 (All valves) 0.9 (G valves) 4.1 (LL valves)	1.9 (All valves) 2.8 (G valves) 0.6 (LL valves)	0.3 (All valves) 0.7 (G valves) 0.2 (LL valves)	1.3 (All valves) 1.0 (G valves) 2.4 (LL valves)
30-day recurrence rate, (% of repaired valves)[a]	b	b	b	17.2 (All valves)
Early failures, (% of repaired valves)[c]	b	b	b	14.3 (All valves)
Overall emission reduction, (% of before maintenance emissions)	b	b	b	71.3 (All valves) 84.5 (G valves) 42.0 (LL valves)
Successful repair, %	b	b	b	29 (All valves)

[a] Leak recurrence within two weeks of repair.

[b] Not determined for individual units.

[c] Recurrence within five days.

Source: Reference 19.

TABLE 4-6. SUMMARY OF ANALYSIS REPORT RESULTS

	Ethylene Units	Cumene Units	Vinyl Acetate Units	All Units
Emission reduction from successful repair, (% of before maintenance emissions)	a	a	a	97.7 (All valves)
Emission reduction from unsuccessful repair, (% of before maintenance emissions)	a	a	a	62.6 (All valves)
Mass emissions from valves screening $\geq$10,000 ppm, %	94 (G valves) 89 (LL valves)	94 (G valves) 80 (LL valves)	90 (G valves) 25 (LL valves)	- -

[a] Not determined for individual units.

Source: Reference 20.

TABLE 4-7. SUMMARY OF RESULTS FOR THE ALLIED HDPE STUDY

30-day occurrence rate, %	3.6 - 7.4 (All valves) 2.6 - 5.6 (G valves) 4.1 - 8.2 (LL valves)
30-day recurrence rate,[a] %	7.8 - 11.1 (All valves) 4.3 - 6.2 (G valves) 9.1 - 12.9 (LL valves)
Successful repair,[a] %	83.3 (all valves) 100.0 (G valves) 78.7 (LL valves)

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[a] Results are based on leaking valves which were successfully repaired for Test 2.

Source: Reference 21.

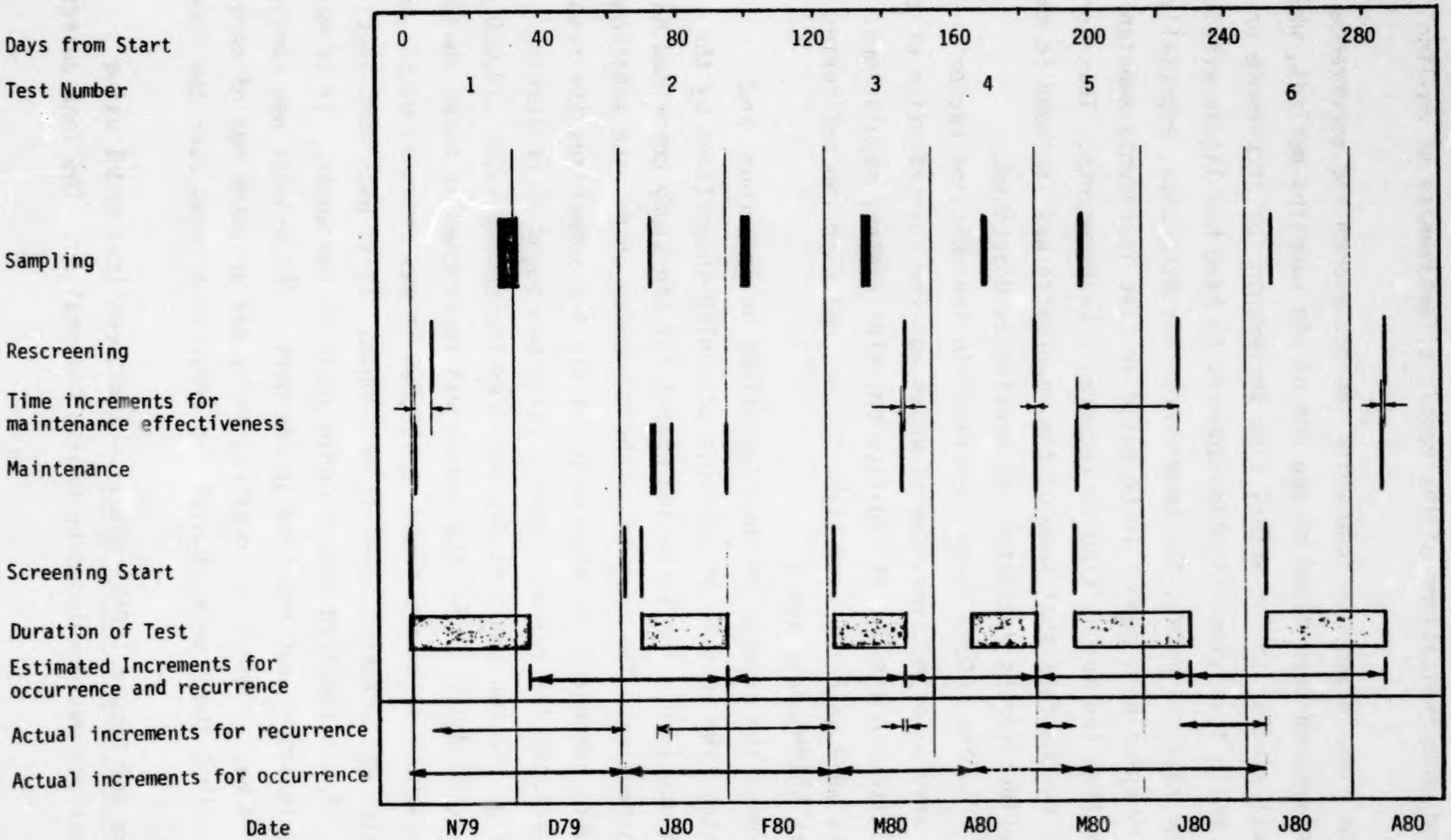

Figure 4-1. Schedule of the fugitive emissions study at the Allied HDPE Unit.
Source: Reference 22.

thus providing good indications of the repair effectiveness of on-line maintenance.

Also, the time increments from which the occurrence and recurrence rates were determined were based on the end of the sampling periods, which were not always similar to the actual time increments for occurrence or recurrence. While this simplification appears to have had little effect on the occurrence rate estimates, the recurrence rate estimates, especially for the last few inspections, appear to be based on time increments substantially larger than the actual time to recurrence measurements. This error is compounded by the fact that some of the recurrence was included in the maintenance effectiveness estimates, as previously discussed.

SCAQMD Study[23] -- The SCAQMD study (described in the emission factor section) had several objectives, one of which was the investigation of the effects on fugitive emissions of fugitive emission control regulations. Screening data were gathered from eight process units in two refineries complying with SCAQMD Rule 466.1.

To determine the effects of the regulations on occurrence and recurrence rates, the results of previous screening inspections by the refinery were obtained. The screening effort for the study comprised an additional inspection. The results of the screening study (the additional inspection) were presented in Table 2-16. Table 4-8 summarizes the results of these inspections for valves. When a valve was found to be leaking (screening value $\geq$10,000 ppm), it was repaired (screening value <10,000 ppm) within two working days. Then, the source was rescreened in three months, and if the screening value was found to >10,000 it was repaired within two days. The valve was screened again in one month. If it was found leaking at this time, it was repaired and screened again in two weeks. If it was found leaking again, it was repaired in one week. The process was continued until the valve was screened and repaired every day or taken out of service. It can be seen that there were significant recurrence rates over the three month interval.

Leak Detection and Repair (LDAR) model -- A mathematical model using recursive equations was developed by Radian Corporation. The leak detection

TABLE 4-8. LEAK OCCURRENCE AND RECURRENCE OF VALVES AND OPEN-ENDED LINES DETERMINED FROM SEVERAL INSPECTIONS - SCAQMD STUDY

Process Unit	Month of Screening	Percent Not Screened	Number Screened	Number[1] ≥10,000	Percent ≥10,000	Number and percent of repaired valves found ≥10,000 at inspection after: 3 Months Number	3 Months Percent	1 Month Number	1 Month Percent	2 Weeks Number	2 Weeks Percent	1 Week Number	1 Week Percent
Alkylation[2]	2/79[3]	10.3	1768	257	14.5	34	13.2	1	2.9	0	0.0	-	-
	7/79[3]	1.1	2043	111	5.4	16	14.4	8	50.0	3	37.5	1	33.3
	9/80[4]	5.2	1931	159	8.2	9	5.7	0	0.0	-	-	-	-
	2/81[3,5]	2.3	1700	153	9.0	0	0.0	-	-	-	-	-	-
Isomax	7/79[3]	5.0	1818	48	2.6	0	0.0	-	-	-	-	-	-
	9/79[3]	4.3	1860	41	2.2	2	4.9	2	100.0	0	0.0	-	-
	10/80[4]	9.0	2322	84	3.6	6	7.1	0	0.0	-	-	-	-
	2/81[3,5]	4.8	1983	47	2.4	0	0.0	-	-	-	-	-	-
FCC[6]	3/79[3]	4.5	1925	79	4.1	15	19.0	2	13.3	1	50.0	0	0.0
	8/79[3]	5.8	1949	24	1.2	4	16.0	4	100.0	0	0.0	-	-
	9/80[4]	6.4	1983	232	11.7	20	8.6	4	20.0	0	0.0	-	-
	2/81[3,5]	9.0	1749	115	6.6	0	0.0	-	-	-	-	-	-
Crude Distillation & Off-Gas Plant[7]	11/79[4]	-	264[8]	4	1.5	0	-	-	-	-	-	-	-
	9/80[4]	-	722	24	3.3	1	-	-	-	-	-	-	-
	3/81[3,5]	29.4	988	19	2.3	-	-	-	-	-	-	-	-
Platformer	11/79[4]	-	233	19	8.2	2	-	-	-	-	-	-	-
	9/80[4]	-	171	6	3.5	-	-	-	-	-	-	-	-
	3/81[3,5]	20.3	396	23	5.9	-	-	-	-	-	-	-	-
Vacuum Distillation	10/80[4]	-	37	0	0.0	0	-	-	-	-	-	-	-
	3/81[3,5]	36.0	242	0	0.0	-	-	-	-	-	-	-	-

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[1] The number of valves with screening values ≥10,000 ppmv reflect the combined effect of occurrence and recurrence.

[2] Records were obtained for the alkylation separator subunit only.

[3] Screening performed with Century OVA 108 calibrated with methane.

[4] Screening performed with Century OVA 108 calibrated with hexane.

[5] Contractor's inspection.

[6] Refinery records do not distinguish between FCC Gas Recovery and FCC Gas Reactor.

[7] Refinery records do not distinguish between crude distillation and off-gas plant.

[8] Does not include any fuel gas valves or curde lines; many rule sources missed.

Source: Reference 24.

and repair model (LDAR) approximates the behavior of fugitive emission sources more closely than the ABCD model presented in the BID. A computer program with variable inputs was prepared for this model.[25] The ability to use variable inputs makes the model flexible for use in many situations.

The model can be used to evaluate programs requiring leak detection and repair of leaking sources at regular intervals (1 month, 3 months, 6 months, 9 months, or one year). The model also includes an option to evaluate a program requiring quarterly inspection of all valves, attempted repair of leaking valves, reinspection of repaired valves monthly until they are determined not to be leaking for two successive months, and repair of leaking valves (including those that could not be repaired within 15 days) during a process turnaround.[a] In addition, the model allows a variable input for repair effectiveness, process unit turnaround frequency, leak occurrence and leak frequency. The model can also incorporate the uncertainty of the inputs and calculate approximate confidence intervals. The details of the model are described in Reference No.26. A brief description of the model is given below.

Figure 4-2 is a schematic diagram of the model (for quarterly screening with monthly follow up on repaired sources). The model is based on the following assumptions:

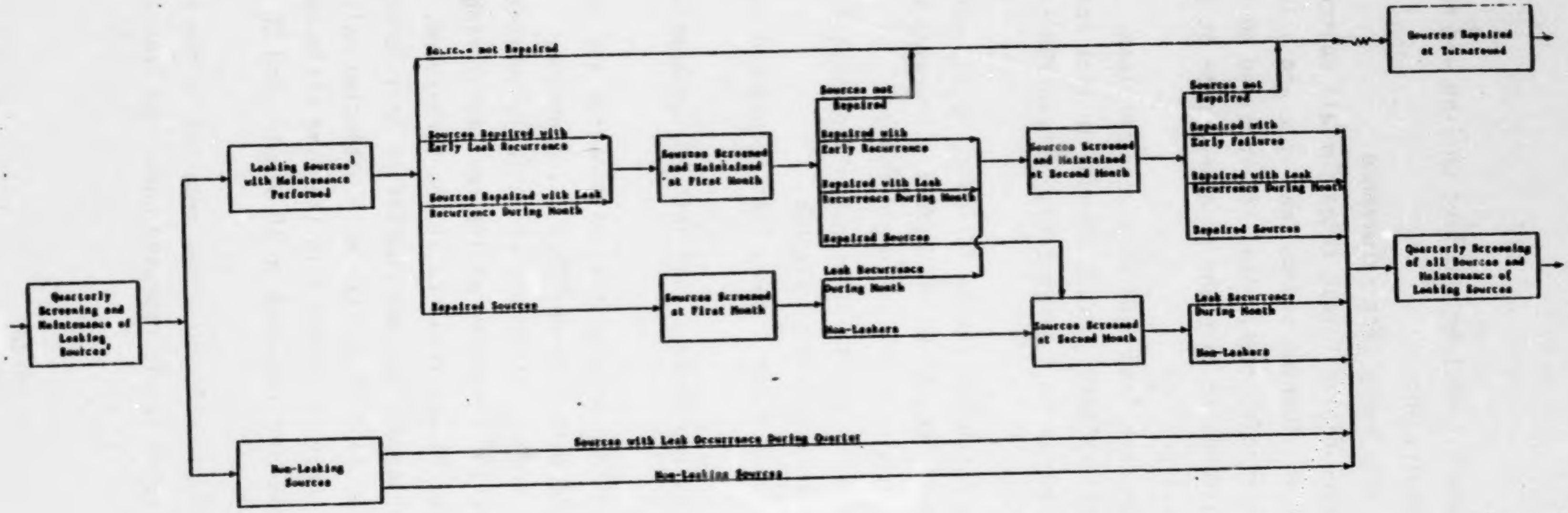
1. All sources at any given time are assumed to be in one of four categories:

   a) Non-leaking sources (sources screening < action level),

   b) Leaking sources (sources screening $\geq$ action level),

---

[a] The model is simplified from the proposed valve standard in one area. In the proposed standard, a source that is repaired must be screened and found to be non-leaking for two successive months before the source is considered to be in the non-leaking source population. The model implements this rule for sources repaired during the quarterly inspection or in the second month of the quarter. But the model only requires that sources maintained in the third month of the quarter are non-leaking during the next quarterly screening. In most cases, the fraction of sources affected should be small, and thus, the impact of this simplification was not considered important enough to further complicate the model.


Quarterly Screening and Maintenance of Leaking Sources[2]
Leaking Sources[1] with Maintenance Performed
Non-Leaking Sources
Sources not Repaired
Sources Repaired with Early Leak Recurrence
Sources Repaired with Leak Recurrence During Month
Repaired Sources
Sources Screened and Maintained at First Month
Sources Screened at First Month
Sources not Repaired
Repaired with Early Recurrence
Repaired with Leak Recurrence During Month
Repaired Sources
Leak Recurrence During Month
Non-Leakers
Sources Screened and Maintained at Second Month
Sources Screened at Second Month
Sources not Repaired
Repaired with Early Failures
Repaired with Leak Recurrence During Month
Repaired Sources
Leak Recurrence During Month
Non-Leakers
Sources with Leak Occurrence During Quarter
Non-Leaking Sources
Sources Repaired at Turnaround
Quarterly Screening of all Sources and Maintenance of Leaking Sources

[1] Leaking sources include all sources which had leak recurrence, had experienced early failures, or had leak occurrence and remained leakers at the end of the preceding quarter.

[2] Except sources for which attempted maintenance was not successful.

Source: Reference 27.

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Figure 4-2. Schematic Diagram of the LDAR Model.

c) Leaking sources which cannot be repaired on-line and are awaiting a shutdown for repair, and

d) Repaired sources with early leak recurrence.

2. There are only three distinct leak rates for all sources. A leaking source leak rate, a non-leaking source leak rate and a leak rate for unrepairable and early recurring sources. That is, repaired sources with early leak recurrence are assumed to have the same leak rate as sources which cannot be repaired on-line.

3. A non-leak has the same leak rate as a repaired leak.

4. The model does not evaluate gradual changes in leak rates over time but assumes that all sources in a given category have the same average leak rate.

5. Effect of time is accounted for as follows: a) all monthly repairs occur at the end of the month; b) the effect associated with the time interval during which repairs occur are negligible.

6. Early recurrences occur essentially instantaneously; i.e., the time from repair to early recurrence is negligible.

7. If a leak stays repaired for a week, leak occurrence rate equals leak recurrence rate.

8. Unsuccessfully repaired sources fall into the unrepaired category instantaneously.

9. Leaks occur (other than unsuccessful maintenance and early recurrences) at a linear rate with time during a given period.

10. When a turnaround occurs, it occurs essentially instantaneously at the end of a quarter, before the beginning of the next monitoring period.

11. All unrepaired sources are repaired at the turnaround. It should be noted that repairs at turnaround are not counted as additional repair attempts in computing the fraction of sources with attempted maintenance because time for complete repair is included in the time estimate for the first attempt, based on 75 percent repaired in 10 minutes and 25 percent repaired in 4 hours.

12. The fractional reduction in emissions reported in the program is determined by comparing emission levels expected under the leak detection

and repair program to the initial level of emissions. The initial level is defined by data collected in the field at operating SOCMI process units.

The significance of the last assumption may not be readily obvious. In the absence of a leak detection and repair program (i.e. uncontrolled) the fraction of valves leaking would increase with time, reaching a maximum at the unit turnaround. If this were the case, the model would compare these "uncontrolled" emissions to those occurring under the leak detection and repair program. However, for valves which are subject to leak detection and repair programs and for other fugitive emission sources which require frequent maintenance, the fraction of sources leaking do not accumulate with time. Instead, periodic maintenance has the effect of causing the fraction of sources leaking and their emissions to increase and decrease in a cyclical manner.

The major implication of this behavior is that when field testing a population of fugitive emission sources which are subjected to periodic maintenance, it is impossible to tell where in the cycle the testing occurred. The field data represent a "snapshot" in time of fugitive emissions. In spite of this obvious shortcoming, the model uses the level of control found in the field as the point of reference against which the effects of a leak detection and repair program are compared. Unless the point of reference is at an average point in the cycle, the LDAR model and other models will underpredict emissions and emission reductions due to leak detection and repair. Furthermore, if the population of fugitive emission sources is near the minimum in the cycle, the measured occurrence rate can exceed the measured leak frequency, and the models may even predict negative emission reductions.

There are two possible ways in which negative results may arise. One possibility is that the units tested actually had programs in place which were more stringent than the leak detection and repair program being evaluated during testing. To perform the testing, the usual program must be abandoned and strict adherence to the program being evaluated must be maintained. If the original program was more effective than the program being evaluated, negative emission reductions would result.

Another possibility is that the program abandoned for testing of the program being evaluated is less effective, but the baseline level measured was measured at a time in the maintenance cycle of the original program when emissions were low. If the maintenance cycle is irregular, it is difficult to judge just where the unit is in the cycle and when emissions can be expected to be low. Maintenance performed just prior to testing, then, could cause negative emission reductions to result even if the original program was not very effective. Maintenance just prior to testing occurred at least once during the 6-Unit Study.[28]

Thus, one of the most important parameters involved in calculating emission reductions is one in which there is a large amount of uncertainty. It is possible to make two sets of comparisons: one to the uncontrolled level and one to the assumed baseline level. The uncontrolled level would be represented by the situation in which leaks are allowed to accumulate in the absence of a leak detection and repair program until the unit turnaround. The baseline level would be the same as the initial level used for comparison in the model (i.e. the level measured in the field). The actual emission reduction would probably be between the two calculated values. Consideration is being given to making such calculations and whether they would provide useful comparisons. At any rate, the present comparisons should be considered conservative estimates of the effects of leak detection and repair programs.

The input parameters required for the LDAR model and the outputs which the model calculates are listed in Table 4-9.

4.1.3 Public Comments

Many of the comments received challenged EPA's estimates of emission reductions achievable by leak detection and repair programs for valves challenged the methodology used to arrive at the estimates. Four major comments were made in this area.

1. Some commenters objected to the use of engineering judgement to arrive at an estimate. Others disagreed with specific judgements.

2. Some of the comments also expressed concern that the emission reduction calculations were done before the SOCMI data were available and that these data would impact the calculations. More specifically, the

TABLE 4-9. INPUTS AND OUTPUTS FOR THE LEAK DETECTION AND REPAIR (LDAR) MODEL

Inputs

1. Emission factor - the initial emission factor for all sources in units of mass/time/source. Note: This input is a key value because it forms the baseline level to which all emissions are compared for calculation of emission reductions. See assumption #12.

2. Occurrence rate - the fraction of sources operating properly at the beginning of the monitoring interval that become leakers during a monitoring interval.

3. Initial leak frequency - the fraction of sources leaking initially (from leak occurrence).

4. Fractional emission reductions from unsuccessful repair - emission reductions for valves for which maintenance did not reduce the screening values to below the action level.

5. Fractional emission reductions from successful repair - emission reductions for valves for which maintenance reduced the screening values to below the action level.

6. Fraction of sources that are leaking and for which attempts at repair have failed - the fraction of sources screening above the action level for which maintenance has failed to decrease the screening value to below the action level.

7. Fraction of repaired sources that experience early failure - fraction of sources which screened above the action level, were repaired to screening values below the action level, and which were screened above the action level within five days.

8. Turnaround frequency - the length of time between plant shutdowns.

Outputs

1. Estimated emission factors by turnaround - the average emissions per source for the period between plant shutdowns in units of mass per time with an approximate 90 percent confidence interval.

2. Fractional reduction in mass emissions by turnaround - the average fractional reduction in emissions for the period between plant shutdowns relative to initial emissions with an approximate 90 percent confidence interval.

TABLE 4-9. (CONTINUED)

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3. Total fraction of sources screened per year - the fraction of sources screened in each year of a five year period.

4. Total fraction of sources with attempted repair during a year - the fraction of sources for which repair is attempted for each year of a five year period. (Note: does not include subsequent maintenance of sources at turnaround.)

5. Fraction of sources screened per month - the fraction of the sources which are screened during each month of a five year period.

6. Fraction of sources with attempted repair per month - the fraction of sources for which maintenance is attempted in each month of a five year period. (Note: does not include subsequent maintenance of sources at a turnaround.)

7. Estimated emission factor for the monitoring interval - average emissions per source for the monitoring interval in units of mass per time.

8. Fractional reduction in mass emissions between monitoring intervals - the average fractional reduction in emissions from the monitoring interval relative to initial emissions with an approximate 90 percent confidence interval.

9. Fractional distribution of leakers due to occurrence - fraction of sources screening below the action level initially which screen above the action level at the end of the monitoring period.

10. Fractional distribution of unrepaired sources - the fraction of sources screening above the action level for which maintenance failed to reduce the screening value below the action level at the end of the monitoring period.

11. Fractional distribution of sources experiencing early failures - fraction of sources screening above the action level which were repaired to screening values below the action level but screened above the action level within five days of repair.

12. Fractional distribution of non-leaking sources - fraction of sources screening below the action level at the end of the monitoring period.

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results of the maintenance study were cited in support of the argument that maintenance effectiveness would be lower than assumed in the BID calculations because on-line valve repair efficiency found in the study was lower than assumed.

3. Of the factors used in the ABCD model for estimating emission reductions achievable, the B factor was the most frequently challenged. Disagreement was expressed with the complex, non-linear occurrence/recurrence relationship assumed in the development of emissions reductions calculations. The leak occurrence/recurrence rates developed in the SOCMI studies[29] were cited in support of this argument. Commenters suggested assuming a linear leak occurrence rate with a proportional recurrence rate or because of the small amount of recurrence data, using only an occurrence rate.

4. Industry commenters submitted a calculation method which they felt more appropriately predicted emission reductions achievable with leak detection and repair programs for valves. Specifically, a mathematical model was recommended to calculate the number of leaks which occur, recur, and remain between monitoring intervals to replace the value of n_m presented in the BID. The industry commenters presented a set of equations (along with their derivations) for calculating this value. This value, n'_m, computed by industry's suggested set of equations is not the same value as used in the BID, which was a function of the fraction of leaks found initially. An example calculation using results (modified in some cases) determined in the maintenance study was also presented.

The following quantities were defined:

P_O = occurrence rate ÷ 100

P_R = recurrence rate ÷ 100

N = percent of sources found leaking initially

Two cases were developed for comparison with the calculations presented in the BID. The first case assumes 100 percent maintenance effectiveness which was also assumed in the BID calculations. The second case takes into account maintenance efficiency based on data from the maintenance study.

Case 1: (assumes 100 percent maintenance effectiveness)

Period	Percent Leakers
t_0	N
t_1	$P_o(100-N) + P_R N$
t_2	$P_o[100-N-P_o(100-N)] + P_R[N+P_o(100-N)]$
t_3	$P_o[100-N-P_o(100-N)-P_o[100-N-P_o(100-N)]] +$ $P_R[N+P_o(100-N) + P_o[100-N-P_o(100-N)]]$

In summary, the rates were calculated as follows:

Period	Percent Leakers
t_o	N
$t_k(k>0)$	$P_o[100-N]S_K(P_o) + P_R[100-(100-N)S_K(P_o)] =$ $100[P_o S_K(P_o) + P_R[1-S_K(P_o)]] + (P_R-P_o)S_K(P_o)N$

where

$$S_K(P_o) = \sum_{i=0}^{k-1} \frac{(k-1)!(-1)^i P_o^i}{(K-i-1)!i!}$$

Case 2: (takes into account maintenance effectiveness less than 100%)
The following definition is necessary for this case:

$$P_m = (\text{maintenance effectiveness}) \div 100$$

This case was considered since the maintenance study data show less than 100 percent maintenance effectiveness.

Period	% Leakers
t_o	N
$t_K(K>0)$	$P_o(100-N)S_K(P_o) + (1-P_m)[100-(100-N)S_K(P_o)] +$ $P_m P_R[100-(100-N)S_K(P_o)] =$ $100[P_o S_K(P_o) + (1-P_m + P_m P_R)[1-S_K(P_o)]] + (1-P_m + P_m P_R-P_o)S_K(P_o)N$

The industry model and the LDAR model are comparable in the general approach to assessing the impacts of leak detection and repair programs on the number of leaks found during any particular monitoring period. They are both based on recursive equations that apply occurrence rate, recurrence rate, and maintenance effectiveness to the population of sources of interest. There are fundamental differences in the assumptions made during the development of the models and in definitions of terms that impact the final form of the equations and the method in which the available data must be applied to the equations. These differences also affect the number of leaks which the models calculate.

A major difference between the models is the handling of leak recurrence. The industry model applies the recurrence rate to all sources that have leaked at some time between turnaround periods. Thus, the occurrence rate is applied only to those sources that have never leaked. Furthermore, the recurrence rate does not include early recurrences (those happening within five days of repair). Early recurrences are considered to be maintenance failure and are accumulated as unrepairable sources. The industry model also does not subject those sources that were successfully repaired to leak occurrence. Basically, when a source has been found to be an unrepairable source, a recurrence, or a fixed source, it remains in that category until the next turnaround.

Although the model suggested by industry and the LDAR model are similar in their general approach, the industry model incorporates some simplifying assumptions that add to the differences described above. The LDAR model is more complex and better represents the expected performance of leak detection and repair programs required by the standards. Where the industry model provides only the number of leaks determined at each monitoring internal, the LDAR model provides the number of sources occurring, recurring, maintained, and those that cannot be repaired. Furthermore, the LDAR model accounts for different emission factors for the different classification of source (unrepairable source, recurring source, occurring source, successfully maintained source) and it can simulate a variety of LDRPs including hybrid monitoring schemes such as quarterly monitoring with monthly follow-up of recently maintained sources. As currently presented, the industry model does not afford this flexibility. The results of this industry model are compared to the LDAR results later in this section.

4.1.4 EPA's Conclusions

Estimating emissions of VOC from fugitive emission sources involves the use of data and engineering judgement. Engineering judgement is used to select the modeling approach and to select the data to use in the model. It is sometimes necessary to select a numerical value which is not based on completely representative data. In this situation the numerical values must be reasonably consistent with the available information or understanding of fugitive emission sources. The analysis presented in the BID necessarily used engineering judgement to select modeling approaches and numerical values. Even though the Agency uses the best modeling approaches and numerical values and improves these as new information becomes available, engineering judgement remains an important part of the estimating process (and appropriately so) no matter which method for estimation is chosen.

To determine how emission reduction estimates for valves should be calculated, EPA had to make two choices: the computational method to be used and the data to use in the computations. The choices made and the reasons for the selections are discussed in the next two subsections. In the last two subsections the results of the analysis are presented and compared to the results from other methods.

Selection of Model for Emissions Reduction Calculations -- Two mathematical models are available for use in estimation of emissions reduction for leak detection and repair programs:

(1) The ABCD reduction efficiency model and

(2) the LDAR model for evaluation of the impact of a leak detection and repair program.

The ABCD model can be used in two different ways:

(a) Using engineering judgement for estimation of n_m (as used at proposal) and

(b) Using the mathematical model presented by the industry for the determination of n'_m.

The ABCD model, especially when combined with the mathematical computation of n'_m presented by the industry, is a straightforward calculation procedure. However, it does not incorporate all the latest information which has been developed concerning fugitive emissions. The addition of the industry recommendation for estimation of n'_m is an improvement in that the B factor is no longer based on engineering judgement. However it is a simplified model and does not necessarily improve the accuracy of the emission reduction estimation procedure. Care must be taken in choosing inputs to the industry model that will be consistent with the assumptions made during its development. Also, the ABCD model does not make provisions for turnarounds. Furthermore, it does not provide for several phenomena which were noted in the field. For example, it does not consider early leak recurrence as a separate phenomenon.

The LDAR model provides these features and also provides the flexibility for evaluating programs such as quarterly monitoring with monthly followup for leakers. It provides additional information, such as the number of valves screened and maintained during each period. Furthermore, it incorporates the phenomenon of early recurrence. The LDAR, therefore, in spite of its relative complexity, has some advantages over the ABCD model and was selected for use in estimating the effectiveness of leak detection and repair programs. A comparison of these results with those of the ABCD model are presented later in this section.

Input data selection -- The second choice to be made was the data to be used in the estimating model. The results of all available fugitive emissions studies were compiled for consideration in making decisions on the data to select for calculations of emission reductions. Table 4-10 presents a summary of the available data on valves. Input parameters that represented the most reasonable estimates for SOCMI units were selected from the available data base. A discussion of the selected inputs and the reasons for their selection is presented below.

1. Emission factors: The estimated emission factors selected are 0.0056 kg/hr for gas valves and 0.0071 kg/hr for light liquid valves. These emission factors were estimated using the leak rates for leaking and non-leaking sources. The details of the estimating procedure are discussed in the emission factors section.

TABLE 4-10. SUMMARY OF AVAILABLE DATA ON VALVES

Study	Occurrence Rate, % (30 days)	Initial Leak Frequency, %	Overall Emission Reduction, %	Emission Reduction From Unsuccessful Repair, %	Emission Reduction From Successful Repair, %	Successful Repair, %	Early Failures, (Recurrence), %	Reference
PR/BID	-	10 (G) 12 (LL)	-	-	-	-	-	30
24-Unit	-	8.2 (All Valves) 11.4 (G) 6.5 (LL)	-	-	-	-	-	31
6-Unit Maintenance	1.3 (All Valves) 1.0 (G) All 2.4 (LL) Units	-	71.3 (All Valves) 84.5 (G) 42.0 (LL)	62.6 (All Valves)	97.7 (All Valves)	29 (All Valves)	14 (17.2) All Valves	32
6-Unit Leak Frequency	-	1 (Unit A) 19 (Unit B) 0.2 (Unit C) 14 (Unit D) 1.1 (Unit E) 17 (Unit F)	-	-	-	-	-	33
Cyclohexane[e]	-	32 (G) 15 (LL)	-	-	-	-	-	34
Chevron Refinery	-	4 (All Valves)	-	-	-	93 (All Valves)	-	35
DuPont[a]	-	6.1 (All) 23.1 (G) 7.1 (LL)	-	-	-	-	-	36
Allied HDPE	3.6-7.4 (All) 2.6-5.6 (G) 4.1-8.2 (LL)	24.7 (All)[b] 17.6 (G)[b] 27.4 (LL)[b]	-	-	-	83.3 (All)[c] 100.0 (G)[c] 78.7 (LL)[c]	(7.8-11.1) (All) (4.3-6.2) (G) (9.1-12.9) (LL)	37

TABLE 4-10. (CONTINUED)

Study	Occurrence Rate, % (30 days)	Initial Leak Frequency, %	Overall Emission Reduction, %	Emission Reduction From Unsuccessful Repair, %	Emission Reduction From Successful Repair, %	Successful Repair, %	Early Failures, (Recurrence), %	Reference
Union Oil[d] Maintenance	-	-	51.8	-	-	50.4	-	38
Shell Oil[d] Maintenance	-	-	76.0 (Test 1) 85.7 (Test 2)	-	-	65.2 (Test 1) 83.3 (Test 2)		39
EPA Refinery Maintenance	-	-	87.0 (Directed Maintenance) 82.4 (Undirected Maintenance)	-	-	88.9 (Directed Maintenance) 56.5 (Undirected Maintenance)	-	40
Phillips Ethylene	-	-	-	-	-	63	-	41
EPA 4-Unit[f]	-	32.5 6.3 6.7 24.3	-	-	-	-	-	42
German Studies	-	-	-	95%	-	-	-	43
SCAQMD	-	-	96 (All Valves)	-	-	100 (All Valves)	-	44

[a] Leak defined as 10 ppm or greater. "All valves" include heavy liquid valves.

[b] Test 1 results only.

[c] Directed maintenance only.

[d] Leak defined as 5300 ppm, OVA - 108 at 1 cm.

[e] Leaks detected by using soap bubbles.

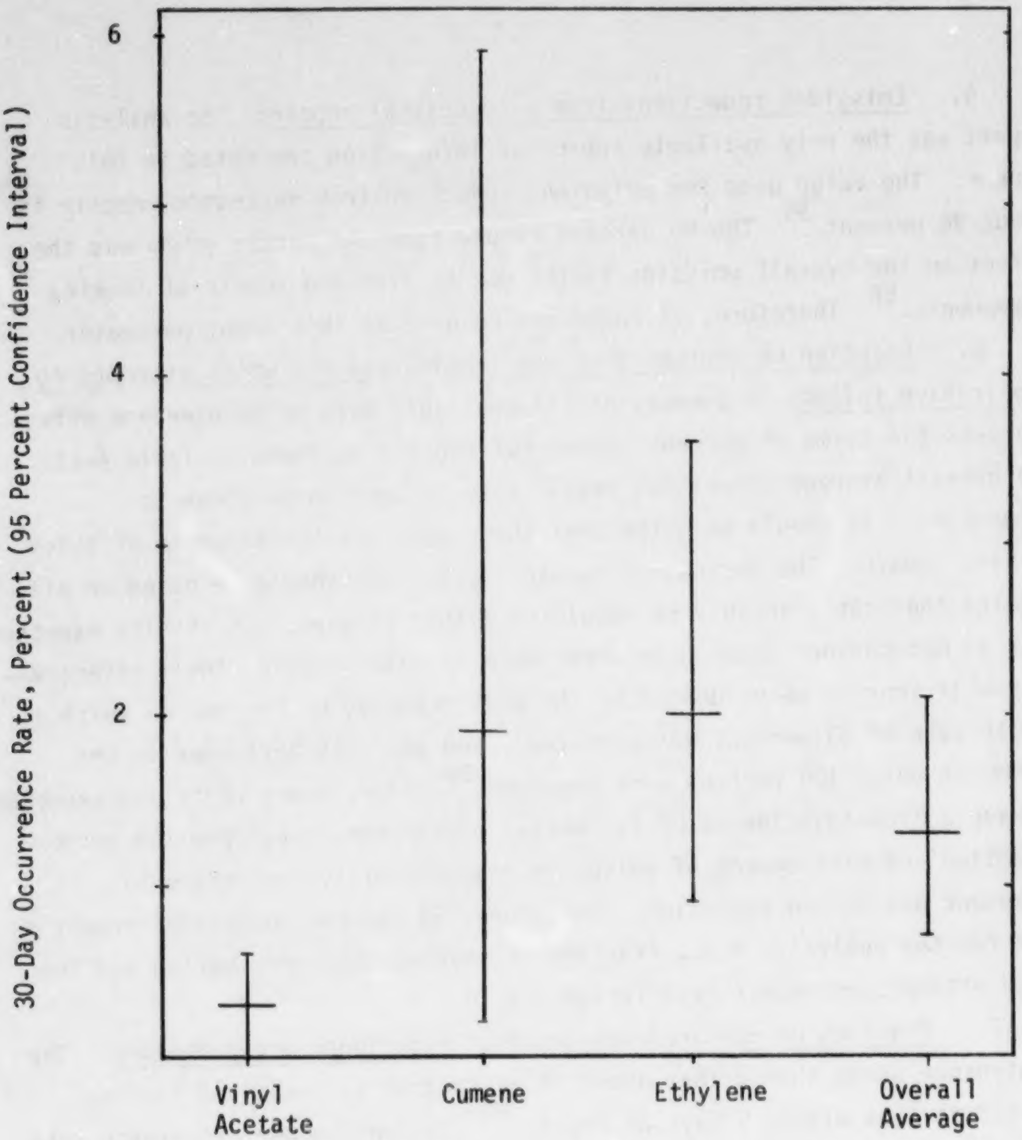
[f] Leak defined as 200 ppm.

[*] 95% confidence intervals.

2. Occurrence rate: Occurrence rate estimates were available from two studies. First, the maintenance study had occurrence rate estimates developed from tests in three SOCMI processes.[45] Estimates were presented for each type of process (vinyl acetate, cumene, and ethylene) and by service (gas, light liquid). An overall estimate for all units was also developed. Second, the Allied study presented occurrence rate estimates for a high density polyethylene unit.[46] Due to some inconsistencies previously noted in this study and due to the broader range of processes covered by the maintenance study, occurrence rates generated in that study were considered to be the best available estimates of occurrence rates for valves. Because the confidence intervals showed substantial overlap, (See Figure 4-3) the overall 30-day occurrence rate of 1.3 percent was selected.

3. Leak frequency: Leak frequency data were available from several studies (see Emission Factors Section). These studies are the Petroleum Refinery study,[47] EPA 24 unit study,[48] EPA 6 unit study,[49] Exxon cyclohexane study,[50] DuPont study,[51] and Allied HDPE study.[52] Some of these studies had leak definitions different from the proposed action level (10,000 ppm). For instance, valve leaks in the cyclohexane study were discovered by using soap bubbles. The DuPont study used a leak definition of 10 ppm. The results of these studies are, therefore, not directly comparable to the rest of the data base. Of the remaining studies the 24 unit study covers the broadest range of processes and was, therefore, considered to be the best available estimate for initial leak frequency for SOCMI. This estimate is 11.4 percent for gas valves and 6.5 percent for light liquid valves. However, there are uncertainties which remain in these values as they are used in the model. These uncertainties were discussed previously in the description of the LDAR model.

4. Emissions reduction from an unsuccessful repair: The results from the maintenance study showed that emissions were reduced by about 63 percent even if the screening value could not be brought down to below 10,000 ppm (i.e., the maintenance was unsuccessful).[53] Since the maintenance study was the only available source of information on emissions reduction from unsuccessful repair, 63 percent was used as the input value.



Source: Reference 54.

Figure 4-3. Valve Leak Occurrence Rates with 95 Percent Confidence Intervals for Processes in SOCMI Maintenance Study.

5. Emissions reductions from a successful repair: The analysis report was the only available source of information presented in this manner. The value used for emissions reduction from successful repair is about 98 percent.[55] The 90 percent figure from the German study was the effect on the overall emission factor due to directed repair of leaking components.[56] Therefore, it could not be used as this input parameter.

6. Fraction of sources that are leaking and for which attempts at repair have failed: A summary of all available data on maintenance effectiveness (in terms of percent successful repair) is shown in Table 4-11. The overall average successful repair rate is seen to be close to 80 percent. It should be noted that these data are for attempts at quick on-line repair. The successful repair input value should be based on all repairs that can resonably be completed within 15 days. It is also expected that as maintenance crews gain experience in valve repair, their effectiveness will improve as evidenced by the work reported by Chevron in which a repair rate of 93 percent was achieved[57] and the work performed in the SCAQMD in which 100 percent were repaired.[58] Also, newer units are expected to have a higher incidence of successful repair resulting from the proper selection and maintenance of valves to reduce fugitive emissions by equipment design and operation. Therefore, 90 percent successful repair is used for the analysis, i.e., fraction of sources that are leaking and for which attempts at repair have failed = 0.10.

7. Fraction of repaired sources that experience early failure: The maintenance study showed that about 14 percent of all repaired sources started to leak within 5 days of repair.[59] The only other recurrence rate data is from the Allied HDPE study.[60] However, that study does not provide information for early failures. Therefore, the maintenance study data were used for input to the model.

8. Turnaround frequency: A two-year turnaround is assumed to be a reasonable estimate for an industry average and is, therefore, used in the calculations. Some units may go longer between turnarounds; some may turnaround more frequently. A two year frequency has been assumed for this analysis.

TABLE 4-11. SUMMARY OF VALVE MAINTENANCE TEST RESULTS

Maintenance Test	Number of Valve Repairs Attempted	Number of Successful Repairs	Percent Repaired
Union	133	67	50
Shell			
March 1979	161	105	65
April 1979	54	45	83
EPA-4 Refineries	32	21	66
Refinery (Ethylene Unit)	46	29	63
EPA-6 unit maintenance	97	28	29
Allied #1[a]	33	14	42
Allied #2	60	50	83
Allied #3[a]	30	18	60
Allied #4[a]	40	17	42
Allied #5[a]	28	16	57
Allied #6[a]	33	15	45
Chevron	1320	1228	93[b]
SCAQMD	382	382	100
TOTALS	2449	2035	
OVERALL AVERAGE SUCCESSFUL REPAIRS			83

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[a] Actual repair effectiveness may be higher than shown. In some cases the valves were not rechecked until 30 days after maintenance.

[b] Simple on-line repairs. Others fixed by more elaborate methods.

Computation Results -- The inputs discussed above were used in the LDAR model to evaluate the effectiveness in reducing fugitive emissions of LDRPs of varying monitoring intervals for control of fugitive emissions from valves in gas and light liquid VOC service. Where possible, the same inputs were also used in the ABCD model, as presented in the BID and as modified to incorporate industry's model for occurrence/recurrence rate estimates. But where engineering judgement was needed in lieu of data, such as for the B-factor in the ABCD model, the original estimate used in the BID was retained. By using equivalent input parameters in the different models, comparisons of the models themselves can be made. A summary of the LDRP effectiveness estimates generated in this manner is presented in Table 4-12. These values represent the overall program effectiveness for gas and light liquid valves for the model units presented in a previous section.

The highest emissions reductions for LDRPs were estimated with the ABCD model presented in the BID. But these values were based on assumed occurrence/recurrence correction factors (B-factors).[61] These B-factors were larger than those derived using the ABCD model with industry's recommended changes, indicating that emissions from occurrence and recurrence and unrepaired leaks are more significant than originally estimated in the BID. Still lower LDRP effectiveness was computed using the LDAR model. The modified-ABCD model and the LDAR model compare closely over the range of monitoring intervals from annual to monthly when implemented with equivalent inputs. They indicate the same trend of increasing LDRP effectiveness with increasing monitoring frequency. In contrast to the ABCD model, the modified-ABCD and LDAR models indicate essentially no emission reduction for the LDRPs with annual monitoring plans.

The ABCD model was executed as it was presented in the BID (See Table 4-13). The theoretical maximum control efficiency (A-factor) and the fractional emission reduction attributed to repair of sources originally screening above the action level (D-factor) were both based on the petroleum refining study and are the same values used in developing emission factors. But the values for A and D presented here differ by a small amount from the values presented in the BID. This discrepancy is due to the fact that an

TABLE 4-12. COMPARISON OF OVERALL LDRP EFFECTIVENESS FOR VALVES IN MODEL SOCMI UNITS[a]

Monitoring Interval	Service	Model		
		ABCD	Modified-ABCD[b]	LDAR[c]
Monthly	Gas	0.93	0.78	0.73
	Light Liquid	0.90	0.62	0.59
Monthly/Quarterly[d]	Gas			0.65
	Light Liquid			0.46
Quarterly	Gas	0.88	0.69	0.64
	Light Liquid	0.85	0.46	0.44
Semiannual	Gas		0.56	0.50
	Light Liquid		0.24	0.22
Annual	Gas	0.78	0.30	0.24
	Light Liquid	0.76	(0.21)[e]	(0.19)[e]

[a] These are overall effectiveness values for LDRPs for gas and light liquid valves in the SOCMI model units presented in a previous section.

[b] Modified to incorporate industry's model for n_m'.

[c] LDAR model presented in Reference 62.

[d] Quarterly monitoring with monthly follow-up of repaired sources.

[e] Numbers in parentheses indicate an estimated negative control efficiency. Negative numbers are generated when the occurrence rate for the monitoring interval exceeds the initial leak frequency. Negative results are subject to interpretation and may not be meaningful.

TABLE 4-13. LDRP EFFECTIVENESS FOR VALVES USING THE ABCD MODEL

Monitoring Interval	Valve Service	A	B[a]	C	D	ABCD
Monthly	Gas	0.998	0.95	0.98	0.999	0.928
	Light Liquid	0.980	0.95	0.98	0.983	0.896
Quarterly	Gas	0.998	0.90	0.98	0.999	0.879
	Light liquid	0.980	0.90	0.98	0.983	0.849
Annual	Gas	0.998	0.80	0.98	0.999	0.781
	Light Liquid	0.980	0.80	0.98	0.983	0.755

[a] These are the same values used in the BID that were based on engineering judgement.

interim report of this study was used in developing the SOCMI BID; the new numbers are based on the final report. Engineering judgement had been used to assign B-factors in the SOCMI BID. Therefore, the B-factors used here were not revised for this estimate.

Input parameters for the modified-ABCD model were chosen to be as nearly equivalent as possible to those used in executing the LDAR model. In executing the modified-ABCD model, the recurrence rate was assumed to be equal to the occurrence rate as in the LDAR model. Early recurrence, as considered in the LDAR model, was incorporated in repair effectiveness in the modified-ABCD model. Since early recurrence was taken as 14 percent and repair effectiveness was 90 percent in implementing the LDAR model, the maintenance effectiveness in industry's model was 90 - 14 = 76 percent. Assuming a two year turnaround cycle, the average number (or fraction) of leaks occurring, recurring, and remaining over a monitoring interval was calculated for gas and light liquid valves, considering various monitoring intervals.

The corresponding B-factors and LDRP effectiveness values which resulted are presented in Table 4-14. The program effectiveness was computed using the same A, C, and D-factors previously discussed and used in the ABCD model. The B-factor incorporated the value for n'_m calculated according to the algorithm submitted by industry using inputs equivalent to those used in executing the LDAR model.

The effectiveness of leak detection and repair programs with various monitoring intervals was calculated with the LDAR model. The overall effectiveness and emission reduction achievable under each plan is presented in Table 4-15. As shown, the highest degree of emission reduction is obtained from monthly monitoring with an overall effectiveness of about 63 percent. The quarterly monitoring plan resulted in a lower effectiveness (about 50 percent), and small differences were seen between the quarterly program and the program incorporating quarterly monitoring with monthly follow-up of repaired sources. The least effective LDRP was an annual monitoring plan that indicated no net benefit.

TABLE 4-14. LDRP EFFECTIVENESS FOR VALVES USING THE MODIFIED-ABCD MODEL

Monitoring Interval	Valve Service	A	B	C	D	ABCD
Monthly	Gas	0.998	0.802	0.98	0.999	0.784
	Light Liquid	0.980	0.652	0.98	0.983	0.616
Quarterly	Gas	0.998	0.709	0.98	0.999	0.693
	Light Liquid	0.980	0.489	0.98	0.983	0.462
Semiannual	Gas	0.998	0.573	0.98	0.999	0.560
	Light Liquid	0.980	0.251	0.98	0.983	0.237
Annual	Gas	0.998	0.304	0.98	0.999	0.297
	Light Liquid	0.980	(0.222)	0.98	0.983	(0.210)

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[a] Numbers in parentheses indicate negative control efficiency. Negative numbers are generated when the occurrence rate for the monitoring interval exceeds the initial leak frequency and may not be meaningful.

TABLE 4-15. LDRP EFFECTIVENESS FOR VALVES USING LDAR MODEL

Monitoring Interval	Valve Service	LDRP Effectiveness	Emission Reductions, Mg/yr Model Unit A	 Model Unit B	 Model Unit C
Monthly	Gas	0.73	3.6	14.5	44.3
	Light Liquid	0.59	4.7	18.8	59.1
Quarterly/ Monthly	Gas	0.65	3.2	12.8	39.3
	Light Liquid	0.46	3.7	14.7	45.3
Quarterly	Gas	0.64	3.1	12.6	38.6
	Light Liquid	0.44	3.5	14.1	43.6
Semiannual	Gas	0.50	2.4	9.8	30.2
	Light Liquid	0.22	1.8	7.2	22.1
Annual	Gas	0.24	1.1	4.6	14.2
	Light Liquid	(0.19)[a]	(1.5)	(6.0)	(18.5)

[a] Numbers in parentheses indicate negative numbers. Negative numbers may be generated when the occurrence rate for the monitoring interval exceeds the initial leak frequency. Negative results are subject to interpretation and may not be meaningful.

4.2 PUMPS

4.2.1 Technical Basis Presented in the BID

As discussed in the BID (EPA-450/3-80-033a)[63], fugitive VOC leaks from pumps used in SOCMI may occur between the shaft and sealing mechanism separating the process from the surrounding environment. The resulting fugitive emissions can be reduced by equipment designed to prevent leakage and by implementing leak detection and repair programs. Both of these techniques were evaluated in the BID and were incorporated in the four regulatory alternatives for light liquid service pumps.

The equipment alternatives for pumps described in the BID include sealless pumps, dual mechanical seals, and seal area enclosures connected to effective control devices. Sealless pumps have no junction between the shaft and pump casing and, therefore, do not leak under normal operating circumstances.

Dual mechanical seals are commonly applied to centrifugal pumps in back-to-back or tandem arrangements. A barrier fluid is flushed between the seals to provide protection against the process fluid leaking to the environment because any process fluid that may be leaked into the barrier fluid would be emitted from barrier fluid degassing reservoirs. Sometimes VOC fugitive emission control by dual seals requires venting of the degassing reservoir to a control device. Although the efficiency of such a system would be dependent upon the efficiency of the control device and the frequency of seal failure, a control effectiveness of 100 percent was used in the BID for dual seal/non-VOC barrier fluid systems. In instances when dual seals might not be applied, enclosing the seal area and venting to a control device was assumed to achieve nearly 100 percent effectiveness in eliminating fugitive VOC losses. These equipment alternatives were taken as the most stringent control option for pumps and represented Regulatory Alternative IV.

Leak detection and repair programs for pumps were also evaluated and were incorporated in the regulatory alternatives presented in the BID. Under Regulatory Alternative II, light liquid pumps would be subject to an annual LDRP, resulting in a 63 percent emission reduction. The monthly LDRP examined as Regulatory Alternative III resulted in an estimated 75 percent control effectiveness. These estimates were made using the same ABCD model discussed previously for valves. The A-factor for pumps was derived from figures for pumps in light liquid service similar to Figure 4-1 of the BID, "cumulative distribution of total emissions by screening values - valves - gas/vapor streams." The leak frequency, N, of 23 percent was taken from Table 4-2 of the BID. The B and C factors were the same as for valves. The D factor was computed in the same manner as for valves.

4.2.2 New Information

Three reports have presented additional data on fugitive emissions from light liquid pumps: Evaluation of Maintenance for Fugitive VOC Emissions Control (6-unit Maintenance Study),[64] Analysis of SOCMI VOC Fugitive Emissions Data (SOCMI Analysis report),[65] and Evaluation of the Maintenance Effect on Fugitive Emissions from Refineries in the South Coast Air Management District.[66] Two of these reports were based on studies conducted in SOCMI units. The SOCMI 6-unit maintenance study presented leak occurrence rates for the three SOCMI process types studied (see Table 4-16). A 30-day leak occurrence rate of 5.5 percent was found for all light liquid pumps in six process units. Recurrence rates and measures of the effectiveness of maintenance were not developed in this study because none of the pumps studied were maintained.

The SOCMI Analysis report presented several observations concerning fugitive emissions from pumps. On-line pump seals had an overall leak frequency of 13.1 percent compared to 4.9 percent for off-line pump seals. No difference in leak frequency was found between double mechanical pump seals and single mechanical pump seals. Data on the barrier fluid systems used were not accounted for in this analysis, however. It is possible that VOC barrier fluids were used in which case VOC would not be emitted from the process fluid to the environment but VOC from the barrier fluid could be.

A preliminary evaluation of the effects of maintenance on fugitive emissions from pumps in refineries was conducted by EPA's IERL in the South Coast Air Quality Management District in California. Screening values were examined as a function of pump seal age and were shown to have a slight

TABLE 4-16. 30-DAY OCCURRENCE RATE ESTIMATES FOR PUMPS

	Number of Sources Followed			
Unit Type	Pumps With Screening Values Less Than 1,000 ppmv	Pumps With Screening Values Between 1,000 and 10,000 ppmv	30-Day Occurrence Rate Estimate	95 Percent Confidence Interval
Cumene	12	3	5.8	(0.7, 20)
Ethylene	31	2	18.4	(2.8, 42)
Vinyl Acetate	39	2	2.8	(0.8, 6.2)
All	82	7	5.5	(2.2, 10)

*A leak from a source was defined as having occurred if it initially screened <10,000 ppmv and at some later date screened $\geq$10,000 ppmv.

Source: Reference 67.

positive correlation. As can be seen from Figure 4-4, almost 90 percent of pump seals are replaced within two years and almost all seals were replaced within two to three years.[68]

4.2.3 Public Comment

Many of industry's comments concerning fugitive emission reductions achievable with pumps were similar to ones made for EPA's estimates of emission reductions for valves. The assumed leak occurrence relationship used in evaluating leak detection and repair programs using the ABCD model was questioned by industry with respect to pumps as well as valves. Industry commenters recommended modification of the ABCD model to incorporate a calculated n_m' value as previously discussed.

4.2.4 EPA's Conclusions

After evaluating the available information concerning fugitive emissions from pumps, EPA found no information which would alter the estimate of the control efficiency expected to be achieved by dual seal/barrier fluid systems. The system, when vented to an efficient control device should achieve virtually 100 percent control, depending on the efficiency of the control device. The option of enclosing the seal area and venting to a control device is also expected to achieve a similar level of control.

The control efficiency of leak detection and repair programs for pumps was reevaluated in light of the Maintenance Study results and the LDAR model. The LDAR model represents a refinement over the ABCD model and the modified ABCD model. And, the data necessary for executing the model are available. EPA saw the chance for making improvements in their estimates of leak detection and repair program effectiveness and, therefore, chose to use the LDAR model.

Table 4-17 shows the available data from which inputs to a leak detection and repair program model could be selected. As shown in Figure 4-5, the confidence intervals for all leak occurrence rates determined in the Maintenance Study overlap. Therefore, the single occurrence rate for all pumps in the study was chosen to represent the typical SOCMI case. This occurrence rate was then adjusted to account for

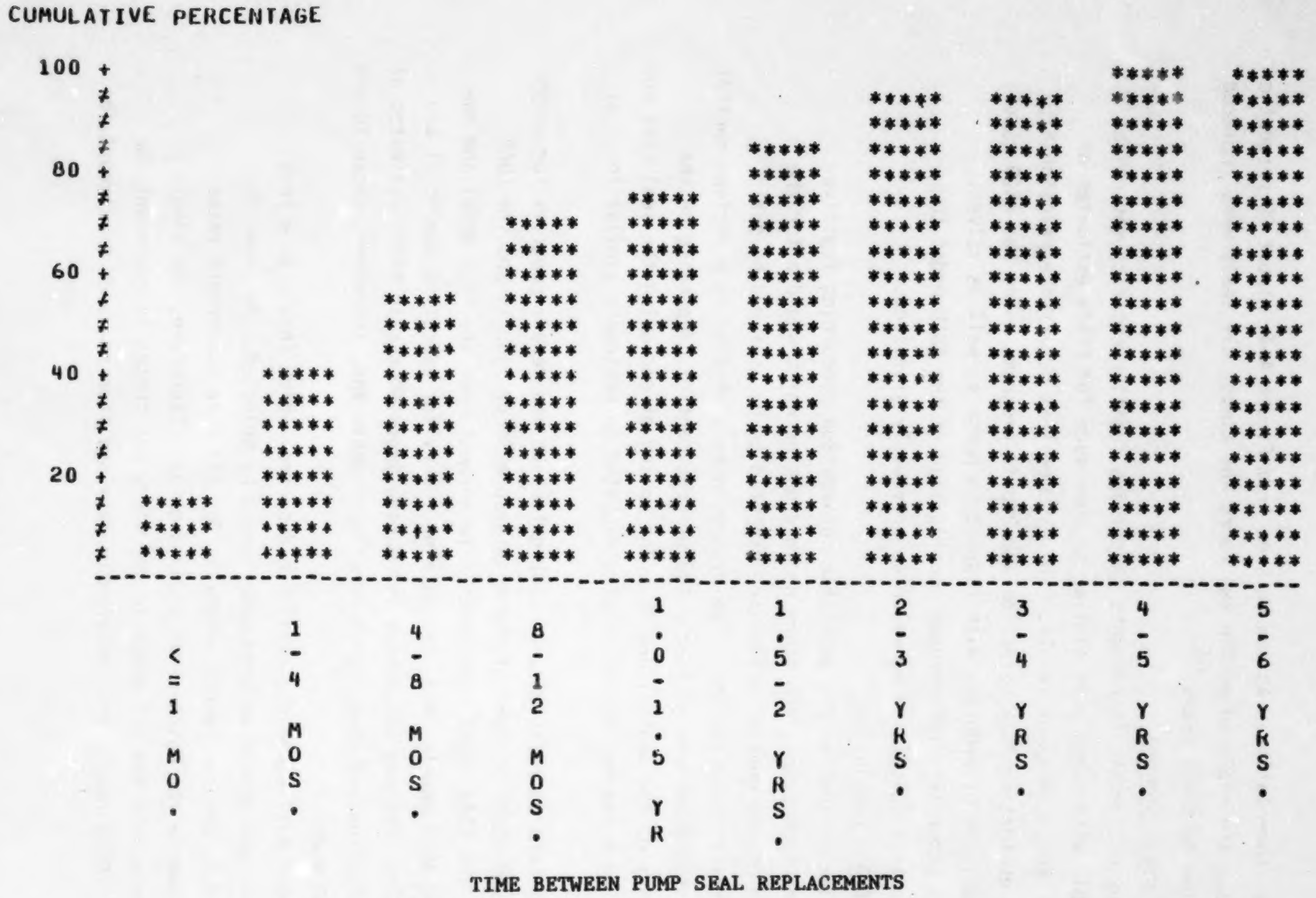
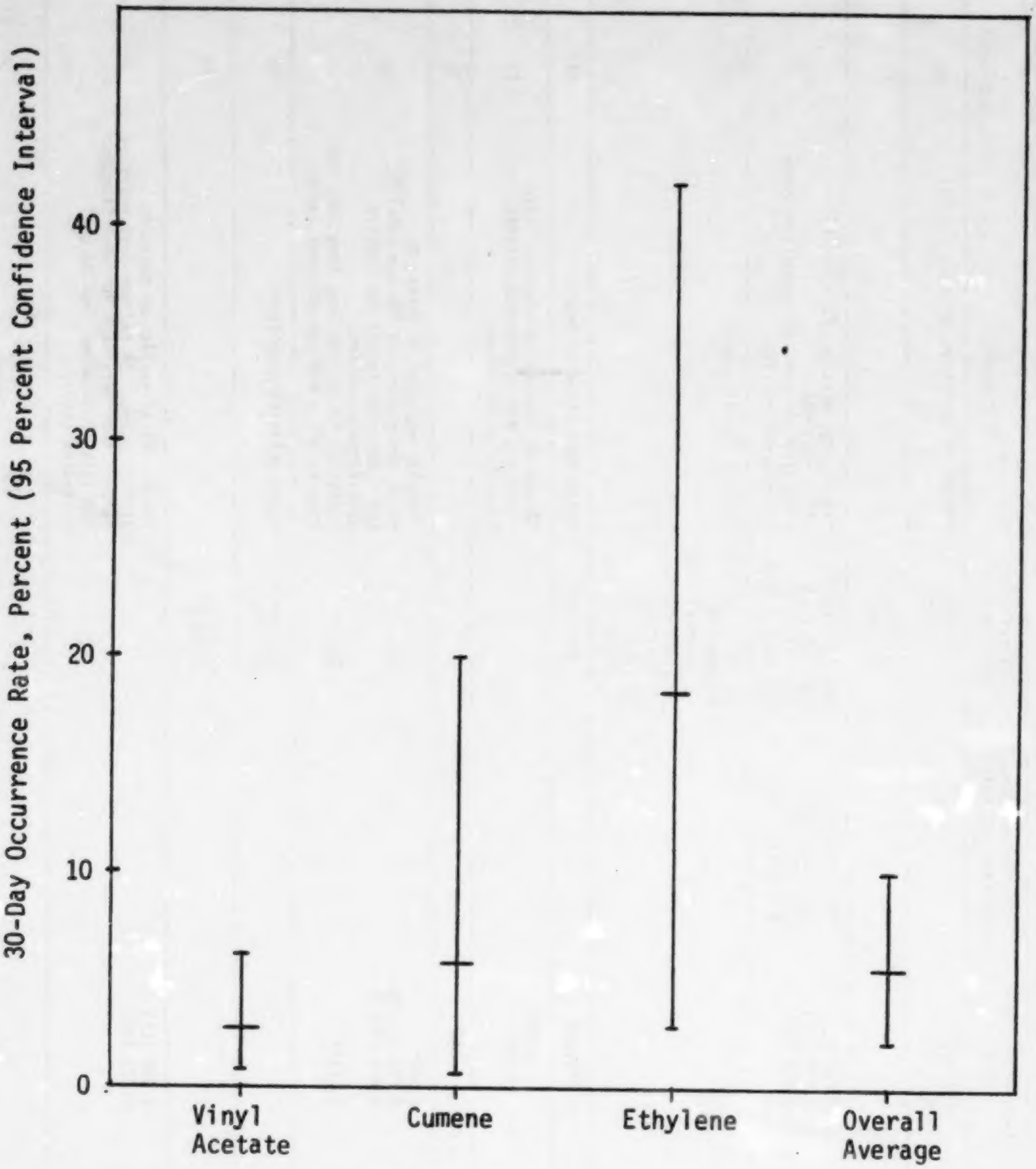


Figure 4-4. Intervals Between Pump Seal Replacements, (Cummulative Percentage), Last Six Years.

Source: Reference 69.

TABLE 4-17. SUMMARY OF AVAILABLE PUMP DATA FOR SOCMI

Data Source	Emission Factor, kg/hr	Occurrence Rate, % (30-day, LL only)	Initial Leak Frequency, %	Comments	Reference
BID*	0.12 (LL) 0.02 (HL)		23 (LL) 2 (HL)	*Based on Petroleum Refinery Studies	70
24-Unit Screening			8.8 (LL) 2.1 (HL)		71
Maintenance Study*	VA:0.002 (LL) CU:0.018 (LL) ET:0.058 (LL)	VA: 2.8 (LL) CU: 5.3 (LL) ET: 18.4 (LL) All Units: 5.5	VA: 6.7 (LL)# CU: 16 (LL) ET: 33 (LL)# All Units: 14.5	*VA = vinyl acetate; CU = cumene; ET = ethylene #Adjusted for shrouded pumps and pumps in methane service.	72
6-Unit Frequency*			15 (Unit A) 21 (Unit B) 3 (Unit C) 33 (Unit D) 3 (Unit E) 10 (Unit F) 17 (All)	*Considered all pumps.	73
Exxon Cyclohexane	0.255(LL)		83 (LL)*	*Leak definition unclear.	74
(Summerfield)*	0.0028# 90% < 0.004			*Based on laboratory studies, field studies, and interpreted results. #Average of 20 values.	75
German Studies	0.006 - 0.063				76
EPA 4 Units	0.029* 0.073 (LEF)# 0.022 (AEF)# 0.011**		23# 5.9**	*Results adjusted in Docket No. ________. #Leak definition was 200 ppm OVA-128; LEF = emission factor for leaking specifically related. *Emission factor and leak frequency not source; AEF = average emission factor.	77
DuPont*			14.3 (LL) 0 (HL)	*Leak definition unclear.	78
SCAQMD			15 (LL) 0 (HL)		79
Estimate*	0.049 (LL) 0.021 (HL)			*Developed in section on emission factors using leak and non-leak emission factors from Petroleum Refinery Studies and leak frequencies from 24-unit screening study.	



Source: Reference 80.

Figure 4-5. Pump Leak Occurrence Rates With 95 Percent Confidence Intervals for Processes in SOCMI Maintenance Study.

seal replacement which normally occurs in SOCMI units. The adjustment was made based on a total seal life of two years. Using a two year average seal life would mean that an average of 4.2 percent of the pump seals were replaced every month. To adjust for the fact that the set of pump seals replaced would not necessarily correspond exactly to those replaced in a leak detection and repair program, only half of the 4.2 percent was included in the adjustment. Then, the 30-day occurrence rate input to the LDAR model became 5.5 - 1/2 (4.2) = 3.4 percent.

The leak frequency determined for light liquid pumps in the 24 unit study (8.8 percent) was chosen as an input to the model since it was based on the most comprehensive data. This leak frequency is also consistent with the emission factor which was chosen from the same data set.

Because leaking pump seals are usually replaced with new seals, all repairs were assumed to be successful. The percent emissions reduction for successful repair of pumps is estimated based on the reduction of emissions from the average leaking source emission rate to the non-leaking source emission rate, resulting in 97.2 percent emissions reduction for replaced seals. It should be noted that this estimate is probably conservative because repair would likely decrease the emission rate to a value lower than the average non-leaking source emission rate. The actual emission reduction will, therefore, probably be greater.

Summary of Input Values -- The parameters selected to be used as inputs to the emission reduction calculations for light liquid pumps are summarized in Table 4-18.

Computation Results -- Using these inputs, the overall effectiveness of leak detection and repair programs for light liquid pumps was evaluated for several monitoring intervals using two of the models discussed previously for valves. The results of these calculations are shown in Table 4-19. As was indicated for valves, the highest effectiveness was estimated using the ABCD model presented in the BID and the lowest values were given by the LDAR model. The higher values computed using the ABCD model were primarily the result of the B-factor assumed for the various monitoring plans.[81] The B-factors used in executing the ABCD model are the same as those presented

TABLE 4-18. SUMMARY OF INPUT DATA FOR CALCULATION OF EMISSION REDUCTIONS DUE TO LDRPs FOR LIGHT LIQUID PUMPS

Occurrence Rate (30-day)	3.4%
Emission Factor	0.049 kg/hr/source
Leak Frequency	8.8%
Emission Reduction for Successful Repair	97.2%
Successful Repair Rate	100%

TABLE 4-19. COMPARISON OF LDRP EFFECTIVENESS FOR LIGHT LIQUID PUMPS

Monitoring Interval	Model		
	ABCD[a]	Modified-ABCD	LDAR
Monthly	0.892	0.759	0.608
Quarterly	0.845	0.443	0.325
Semiannual		0.075	(0.076)
Annual	0.751	(0.347)	(0.800)

[a] The B-factor used in the BID analysis was based on engineering judgement and was, therefore, retained in this analysis. The other factors were computed based on the best available data, as presented in Table 4-13.

Note: Numbers in parentheses indicate negative control efficiency. Negative numbers will be generated when the occurrence rate over the monitoring interval exceeds the initial leak frequency and may not be meaningful.

in the BID. Since they had been based on engineering judgement and not computed, there was no reason to update the values with new judgements. Because a method had been devised for estimating the other factors (A, C, and D), however, they were updated using the inputs established for the LDAR model. Also, by using the industry model for occurrence/recurrence rate estimates, new B-factors were computed that resulted in lower effectiveness when the modified ABCD model was executed. The discrepancy between the estimates for the ABCD and modified-ABCD models became larger with decreasing monitoring frequency. And still lower program effectiveness was estimated using the LDAR model.[82]

Both the modified-ABCD and LDAR models predicted negative program effectiveness values for long monitoring intervals. This anomaly is caused by the comparison of emissions resulting when a leak detection and repair program is in place to emissions indicated by the initial fraction of sources leaking. As explained earlier, there is much uncertainty in fixing this baseline for purposes of comparison. As further explained, if the measured occurrence rate for the given monitoring interval exceeds the initial leak frequency, the models may predict negative emission reductions. It should be noted that both of these models did indicate decreasing effectiveness with increasing monitoring interval. The impact of a pump LDRP on emission reductions in model units is present in Table 4-20 for LDAR estimates.

4.3 SAMPLING SYSTEMS, OPEN-ENDED LINES, COMPRESSORS, SAFETY RELIEF VALVES

4.3.1 Technical Basis Presented in the BID

Various control techniques were examined for sampling systems, open-ended lines, compressors and safety/relief valves in the BID. These control techniques which were incorporated in the regulatory alternatives are shown in Table 4-21. The control techniques considered included leak detection and repair programs (LDRPs), equipment, and combinations of equipment and LDRPs. The type of control evaluated for each source depended upon the leak characteristics of the source.

As explained in the BID, emissions from sampling systems primarily result from purging of liquid trapped in sample lines. These emissions will

TABLE 4-20. LDRP EFFECTIVENESS USING LDAR MODEL FOR PUMPS IN LIGHT LIQUID SERVICE

		Emission Reductions, Mg/yr		
Monitoring Interval	LDRP Effectiveness	Model Unit A	Model Unit B	Model Unit C
Monthly	0.61	2.1	7.6	23.9
Quarterly	0.33	1.1	4.1	12.8
Semiannual	(0.076)	(0.3)	(1.0)	(3.0)
Annual	(0.80)	(2.8)	(10.0)	(31.5)

Note: Numbers in parentheses indicate estimated negative control efficiency. Negative numbers will be generated when the occurrence rate over the monitoring interval exceeds the initial leak frequency. These values are subject to interpretation and may not be meaningful.

TABLE 4-21. REGULATORY ALTERNATIVES FOR SOME FUGITIVE EMISSION SOURCES IN SOCMI

	Regulatory Alternative[a]					
	II		III		IV	
Source	Monitoring Interval (% Efficiency)	Equipment Specification (% Efficiency)	Monitoring Interval (% Efficiency)	Equipment Specification (% Efficiency)	Monitoring Interval (% Efficiency)	Equipment Specification (% Efficiency)
Sampling Systems	None (0)	None (0)	None (0)	None (0)	None (0)	Closed loop sampling (100)
Safety/relief valves-gas	Quarterly (59)	None (0)	Monthly (62)	None (0)	None (0)	Upstream Rupture Disks (100)
Open-ended lines - gas	Quarterly (86)	Caps, etc. (100)	Monthly (90)	Caps, etc. (100)	None (0)	Caps, etc. (100)
Open-ended lines - light liquid	Annually (62)	Caps, etc. (100)	Monthly (74)	Caps, etc. (100)	None (0)	Caps, etc. (100)
Open-ended lines - heavy liquid	None (0)	Caps, etc. (100)	None (0)	Caps, etc. (100)	None (0)	Caps, etc. (100)
Compressors	Quarterly (72)	None (0)	Monthly (76)	None (0)	None (0)	Seal area/degassing vents to control device (100)

[a] Regulatory Alternative I was uncontrolled for all sources.

Source: Reference 83.

also depend upon the frequency of sampling. By using closed loop, or closed purge, sampling systems where the purge VOC is returned to the process, purge emissions can essentially be eliminated. A control efficiency of almost 100 percent, therefore, was assumed to be attainable.

Open-ended lines are primarily drain, purge, sample, and vent valves. The emissions through the seat of these valves were assumed to be eliminated by installing plugs, caps, blinds, etc. Plugs, caps, etc, were, therefore, chosen as the equipment requirement for open-ended lines. In the BID, emissions estimates for open-ended lines included emissions through the seat as well as emissions around the stem of the associated valve. Therefore, a combination of equipment and LDRP was considered. The fugitive emissions around the stem of the valve would be controllable under the LDRPs assumed for in-line valves. These programs and their effectiveness in reducing emissions were discussed in detail in the section on emission reductions for valves.

Fugitive emissions from compressors can result from seal failure. As part of the regulatory analysis, two LDRPs were considered for compressors: quarterly and monthly monitoring. The efficiencies of these programs were estimated by the ABCD model to be 72 percent and 76 percent, respectively. Regulatory Alternative IV for compressors consisted of a mechanical seal with non-VOC barrier fluid system. An efficiency of 100 percent was used for such a system because the emissions from the degassing reservoir were sent to a control device.

The three control techniques evaluated in the regulatory alternatives for safety/relief valves in gas service were LDRPs of quarterly and monthly monitoring intervals and control equipment. Emissions from safety/relief valves result from failure of seating surfaces, improper reseating after a release, and "simmering" due to processes operating too near the set pressures of the valves. Reduction of fugitive emissions from safety/relief valves requires removal of the leaking valve for repair or replacement. Even after effecting repairs, elimination of leaking after another overpressure is not ensured. The effectiveness of LDRPs for safety/relief valves was estimated to be approximately 60 percent using the ABCD model previously described. Equipment considered in making the selection included rupture disks, soft-seated (O-ring) relief valves and piping of relief valve exhaust to a flare or other combustion device.

4.3.2 New Information

Since proposal, additional information has become available only for open-ended lines. Information on the effectiveness of repair of open-ended lines was gathered in the SCAQMD in a study of fugitive emissions in refineries subject to Rule 466.1 of that district in California.[84] Of the open-ended lines screened, 86 percent were sealed by means of plugs, caps, blinds, or second valves. These sealed open-ended lines leaked at a frequency of 4.0 percent, while those not sealed had 9.0 percent leak frequency. Repair of leaking sources was attempted during this study. The emission reduction achieved was 97 percent.

4.3.3 Public Comment

Industry commenters questioned the emission reductions estimated for two of the four fugitive emissions sources discussed in this section: safety relief valves and sampling systems.

1. Commenters disagreed with the assumption that the installation of a rupture disk beneath a relief valve eliminates leakage. They said that considerable leakage can occur at the gaskets between the disk holder and the mating of the valve.

2. The emission reductions estimated for sampling systems were also questioned. One commenter noted that there are typically four valves associated with sampling systems and that emissions from these valves easily exceed the emissions estimated for sampling systems. Another pointed out that a 100 percent control efficiency is not realistic, since VOC would be retained and lost from coupling points around the sample container.

4.3.4 EPA's Conclusions

EPA reviewed the information available concerning emission reductions achievable by the control techniques for sampling systems, safety relief valves, open-ended lines, and compressors. Rupture disks can be used to eliminate leakage from safety relief valves. When they fail, they are replaced, so that fugitive emissions will not occur. The emissions reductions being considered are emissions through the valve seat, not emissions from flanges. Moreover, EPA test results show fugitive emissions from flanges to be low. Therefore, the estimate of 100 percent control efficiency is appropriate. Similarly, emissions from capped open ends would approximate those of flanges and are anticipated to be low, especially in comparison to the emissions expected from the valve seat and the open end.

EPA realizes that a small amount of VOC may be lost when sampling connections are broken on a closed purge sampling system. This amount of VOC is so small compared to the volume of sample purge, however, that the overall control efficiency approaches 100 percent. Fugitive emissions from valves associated with the sampling system would be controlled by the LDRP for valves and should not affect the emission reductions achieved by eliminating the purge stream. Thus, the estimates in the BID are considered appropriate. Furthermore, any sampling system closed purge or otherwise will have valves and when these are properly controlled by a leak detection and repair program, their emissions will be minimized.

In addition to reevaluating the control efficiencies estimated for equipment, EPA considered the emission reduction estimates for LDRPs for safety/relief valves and compressors. The applicability of leak detection and repair programs to compressor seals would be of limited use considering the effectiveness of equipment techniques. If a compressor is found leaking, the repair procedure would be the installation of control equipment. Because compressors are not generally spared, repair would be delayed until the next turnaround, thereby reducing the effectiveness of a leak detection and repair program to essentially zero.

Leak detection and repair programs, however, may be a viable control alternative for safety/relief valves. Two methods of estimating LDRP effectiveness were considered. First, the ABCD model with values presented in the BID could be applied. These estimates were based on assumptions that may not be representative of the actual situation, considering the comparison of model results for valves and pumps. The results of this model are given in Table 4-21. The second approach would be based on the LDAR model. The LDAR model is a better indicator of program effectiveness than the ABCD model presented in the BID. In order to evaluate the effectiveness of LDRPs in reducing emissions from any source using the LDAR model, the following data would be needed:

1) emission factors,
2) leak frequencies,
3) leak occurrence rates,
4) leak recurrence rates,
5) rate of successful repair,
6) emissions reductions due to successful repair, and
7) emissions reductions due to unsuccessful repair.

Of these data, only leak frequencies and estimated emission factors are available for safety/relief valves. Because all the data necessary for evaluating LDRPs for safety/relief valves are not available, the LDAR model cannot be applied directly using data on safety/relief valves alone. In lieu of these data, LDAR results for gas valves were compared to ABCD results for gas valves in developing a revised estimate of LDRP effectiveness for safety/relief valves in gas service. The LDRP effectivness for safety/relief valves was estimated using the effectiveness for gas service valves based on the LDAR model multiplied by the ratio of the effectiveness for safety/relief valves based on the ABCD model to the effectiveness for gas service valves based on the ABCD model. This is in essence a rejudgment of the B-factor in the ABCD model based on the results of the LDAR model for valves in gas service. A comparison of these estimates is presented in Table 4-22.

4.4 CONTROL DEVICE

4.4.1 Technical Basis Presented in the BID

As explained in the BID, several control devices were considered for control of fugitive VOC emissions.[85] These devices included thermal incinerators, process heaters, and vapor recovery systems, such as carbon adsorbers. As reported in the BID, through proper design and operation, carbon adsorption systems reportedly achieve 95-99 percent control efficiency.[86] Condensation systems can also achieve VOC capture of 90 percent or better.[87] Carbon adsorption systems generally achieve constant concentrations of VOC in the exhaust stream, based on the specifics

TABLE 4-22. COMPARISON OF LDRP EFFECTIVENESS FOR SAFETY/RELIEF VALVES BASED ON ABCD AND LDAR MODELS

Monitoring Interval	Model Basis	
	ABCD[a]	Estimated LDAR[b]
Quarterly	0.59	0.44
Monthly	0.62	0.50

[a] Effectiveness presented in Table 4-21 and in the BID.

[b] LDAR effectiveness for gas valves multiplied by the ratio of ABCD effectiveness for safety/relief valves to ABCD effectiveness for gas valves.

of the adsorption bed design and gas stream conditions. Thus, the efficiencies will depend upon the inlet concentration of VOC in the gas stream, as well as the system design. But, considering the VOC exhaust streams from fugitive emission sources (except safety relief valves) most vapor recovery systems in a process unit can achieve greater than 95 percent control.

Achievable VOC destruction efficiency by thermal incineration was evaluated using EPA, industry, and Los Angeles County incinerator test data. Data from a laboratory incinerator were also compared to actual field test results. Based on an analysis of these data, it was concluded that new incinerators could achieve 98 percent control efficiency or 20 ppmv by compound exit concentration, whichever is less stringent.[88]

The use of flares was also considered in the BID. The efficiency of flares in eliminating VOC is not well established and there is no approved EPA reference method for establishing flare performance. Efficiencies reported in the literature ranged up to 99 percent. But, based on theoretical calculations, an estimate of only 60 percent efficiency had been made for a flare used on a vent stream in an ethylbenzene/styrene plant (EPA-450/3-79-035a).[89] The estimates of destruction rates were based on the "Afterburner Systems Study" by Shell Development Company (EPA-R2-72-062)[90] and represented a generalized correlation for hydrocarbons combusted at 1410°F.

Design requirements were then considered to ensure that control devices would achieve a desired VOC destruction. The temperature and residence time specified for enclosed combustion devices in the proposed standards were based on data analyzed in an EPA memo ("Thermal Incinerators and Flares") dated August 22, 1980.[91] The data base contained in this memo included Union Carbide laboratory studies, EPA and industry field tests, and 147 tests on incinerators in Los Angeles county. These data indicate that greater than 98 percent efficiency is attainable by all new incinerators operating at 1500°F (816°C) and 0.75 seconds residence time. The memo concludes that 98 percent efficiency, or less than 20 ppmv, is achievable in many situations at less than 1600°F (871°C) and 0.75 seconds residence time.

While thermal incinerators are proven control devices for destruction of VOC emissions, they are not the only enclosed combustion devices that could be used. In fact, boilers and process heaters are expected to be used for eliminating the small VOC streams covered by the standards. Other systems, such as catalytic incinerators, and vapor recovery systems are also applicable to control of these streams.

A control efficiency of at least 95 percent was chosen as the design requirement because it is a reasonable control efficiency which is achievable for vapor recovery systems such as carbon adsorption or condensation units used for fugitive emission sources. This control efficiency can be achieved by boiler furnaces, incinerators, process heaters, and carbon adsorption units.[92]

4.4.2 New Information

A study was undertaken for EPA by Battelle Memorial Laboratories in order to develop a methodology for measuring flare performance.[93] This program was carried out in conjunction with John Zink. Although the program was to develop flare test methods and was not specifically designed to provide flare performance data, the data gathered during this development program indicate that properly designed and operated flares may attain from 94 to 99+ percent local burnout efficiency. Both the single air-augmented flare and the flare consisting of three multi-stage burners attained local destruction efficiencies of greater than 99 percent under normal operating conditions. When the single flare was operated without supplemental air (nonsmokeless operation), the local destruction efficiencies measured were greater than 94 percent, with an average of about 96 percent. As was the case in the Siegel flare study,[94] the efficiencies measured were local burnout efficiencies, not overall flare efficiencies.

4.4.3 Public Comments

A number of comments were received after proposal concerning the use of flares and the performance level achievable by them. Chemical producers, with a long history of flare use, stated that flares are efficient control mechanisms capable of achieving 95-99 percent VOC destruction efficiency. They cited as their primary support a 1980 study of flare conversions in refinery flares by K.D. Siegel.[95] Based on this efficiency estimate, they said that flares should be considered equivalent control devices to the other accepted techniques (thermal incineration, vapor recovery). Efficiencies greater than 95 percent were cited in the literature for newer flaring techniques, such as multistage flares and flares with air or steam premixing. Multistage flares result in improved efficiency since variable flowrates are handled in stages, keeping close to design conditions. Commenters also expressed concern that time and temperature requirements precluded the use of catalytic incinerators.

4.4.4 EPA's Conclusions

To date, four studies of flare performance that have been conducted include a 1972 study of ethylene destruction by flares conducted by DuPont, a 1980 study of flare conversions by K.D. Siegel, a recent flare study by Union Carbide, and the John Zink flare study recently conducted for EPA by Battelle Memorial Laboratories. Each of the studies is discussed below with respect to the discussion on control devices in the BID.

DuPont study.[96] In 1972, DuPont conducted a series of tests on a bench-scale flare to develop sampling procedures applicable to large flare systems. Ethylene was used as the waste gas stream; helium was used as a tracer gas so that air dilutions in the combusted gas stream could be determined. The flare efficiency was assumed to be equal to the ethylene destruction efficiency.

Flame lengths measured during test runs without steam addition corresponded to those estimated by currently accepted empirical relationships such as presented in the API reference RP-521.[97] The measured flame lengths demonstrated no apparent dependence upon gas velocity, indicating that flame length was bouyancy-dependent. With the addition of steam, flame length was reduced and its characteristics changed from long, reddish, and smokey to short and yellow. This is an indication of improved combustion due to better oxidation and probably higher flame temperature (these temperatures were not measured).

The quantitative utility of these data is limited for the following reasons. (1) The analysis used did not consider total hydrocarbons in determining flare efficiency; it considered only ethylene destruction. Although all ethylene fed was destroyed by the flare, one series of tests indicated that higher molecular weight hydrocarbon tars were produced. Taking these compounds into account, the flare efficiency based on total hydrocarbon destruction would be lower than the 100 percent reported. (2) All data collected during the study were in the turbulent flow region. This situation represents the design case for a flare system, i.e. emergency venting. Flares designed for emergency venting and operated for fugitive emission control might be represented better by a lower flow region. (3) Finally, the results of the tests on steam addition are inconclusive in terms of flare efficiency. The limited data do not allow for quantitative analysis of steam addition on efficiency.

Siegel flare study.[98] An extensive study of an industrial flare was presented by K.D. Siegel in February 1980. The study considered the conversion of flare gas with varying gas composition, steam addition rate, and crosswind conditions. Approximately 1300 data points were collected during 12 test runs made on the flare. But this number of data points is misleading. The data describe point conditions for contours around the flame region for various elevations. No evaluation of overall flare efficiency is presented. All of the data collected were for flow conditions in the turbulent region (although most of the data was collected in the lower end of this region). As previously mentioned, lower flow regions may be more representative of fugitive emissions venting from a flare designed for emergency situations. One of the most significant limitations of Siegel's data is the flare design used; his design allowed a degree of air-fuel premixing prior to the flare tip exit. This is atypical of the majority of the flare designs used on industrial applications in the United States.

In a previous review of Siegel's paper[99] EPA pointed out limitations in the gas compositions and carbon balancing used. The high concentration of hydrogen (about 50 percent), low concentration of hydrocarbon, and relatively high BTU content (over 1000 Btu/scf) of the flare gases used by Siegel are not commonly found in the chemical industry. These characteristics also promote high combustion efficiency. EPA further noted that a carbon mass balance could not be made.

Based on these points, the quantitative results of Siegel's flare study are of questionable utility and applicability to the flares used for fugitive VOC streams. But there are some useful results of this study. Siegel does examine the relationship between the measured visible flame length and existing flame length correlations (applicable to turbulent flow conditions). His results also indicate enhancement of flare efficiency with increasing steam addition.

Union Carbide Study.[100] Researchers at Union Carbide Corporation presented the initial results of a study of flare destruction efficiency. This study was focused on obtaining a better understanding of the fundamentals of hydrocarbon destruction in a flare; establishing a quantitative flare efficiency was not the primary intent of the study. Two bench-scale flares (1/8 inch diameter and 2-inch diameter) were used to burn a propane fuel gas. Helium was used as the tracer gas so that air dilutions of the flared gas could be determined. For all cases, no steam-enhancement was used and the resulting flame was sooty.

Both continuous and integrated grab sampling was used and propane destruction efficiencies determined. The local burnout efficiencies reported for the 2-inch flare ranged from 95.8 percent to greater than 99.9 percent. These values must be considered in a qualitative sense only since some sampling problems were encountered during the study and some samples were taken from eddy flames that were still burning.

John Zink flare study.[101] EPA issued a contract to Battelle Memorial Laboratories to develop measuring techniques for use on flare systems. The Battelle study was just recently conducted on a John Zink flare facility. Since this program was conducted to develop the measurement techniques for use on flares, the results have questionable applicability to the SOCMI-Fugitive VOC Emissions NSPS development. This is not a comprehensive study of flare efficiency; rather, limited testing was conducted to evaluate emission measurement techniques.

These studies were conducted on two different flare systems and employed two techniques for measuring the destruction efficiency of each system. The major portion of testing was conducted using an air-augmented single flare burning commercial grade propane at between 3000 and 5000 pounds per hour. A limited number of tests were conducted to determine the horizontal and vertical profiles of the emissions envelope, the emissions under normal operating conditions, and the emissions under nonsmokeless operation (no supplemental air provided). The second flare system tested consisted of three burners mounted in-line; these burners were of the type generally used in multistage flare systems. Natural gas was burned in the second system at between 2000 and 3000 pounds per hour. For normal smokeless operation, both flare systems demonstrated destruction efficiencies greater than 99 percent. The nonsmokeless operation of the single flare resulted in destruction efficiencies greater than 90 percent for an average efficiency of about 96 percent.

Agency Conclusions -- Reviewing available data and literature, EPA determined that control devices in new installations should be capable of attaining better than 95 percent efficiency in reducing VOC emissions. EPA's review of thermal incinerators concluded that new incinerators should achieve at least 98 percent efficiency or 20 ppmv VOC in the exhaust stream, whichever is the less stringent requirement.[102] Similarly, carbon adsorption systems in new installations can be designed and operated to attain at least 95 percent removal of VOC.[103] The use of carbon adsorption would be more limited in this application than incineration, but would provide a recovered product.

Furthermore, EPA has determined that smokeless flares may be capable of achieving 90 percent or better control efficiency. Although most data reported show 95 percent (or over) combustion efficiency for flares, there is considerable uncertainty whether this efficiency is applicable to plant flares. These uncertainties arise from the following areas:

1) Composition and heat content of the flared stream - the tests that have been conducted were on streams with heat contents of about 1,000 Btu/scf. Some plant flares burn gases with heat contents below this and occasionally go out due to a low heat content (less than 160 Btu/scf).
2) Size of flares tested - the flares tested were small units, the largest burning less than 7,000 lb/hr of gas. Since some industrial flares are sized to combust 900,000 lb/hr, the air required for complete combustion may not be as effectively supplied by thermal draft effects as it is in the smaller flares.
3) State of tested flares - the plant-sized flares tested were highly maintained state-of-the-art flares. This degree of technical attention is not expected for most plant flares. And reduced maintenance could result in decreased efficiency due to incomplete mixing and by-passing of the flame.

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5. COST ESTIMATES

This section presents the cost estimates and the input parameters affecting the cost estimates for each of the fugitive emission sources presented in the Background Information Document (BID). Also discussed are the new information and the public comments regarding these estimates and any changes in the estimates due to the new information or the comments. All costs are presented on a last quarter 1978 basis.

5.1 VALVES

5.1.1 Technical Basis in the BID

The cost for leak detection and repair programs for valves were calculated in the BID. The factors affecting the total cost of a leak detection and repair program are (1) monitoring time, (2) repair time for on-line and off-line repair, and (3) fractions of leaks repaired on-line and off-line. The following estimates were used for the above:

(1) Monitoring time: The time required to monitor leaking valves was available from several sources. Exxon Company, U.S.A. conducted an in-depth study to determine the monitoring manpower requirements.[1] Five Exxon refineries conducted field surveys using Bacharach and Century Systems analyzers to determine the time required for monitoring various fugitive emissions sources. The average monitoring time for a leak detection survey for valves was found to be 2 man-minutes per valve. In the EPA 24-unit study[2] the actual monitoring time was found to be considerably less than that estimated using the 2 man-minute monitoring time for valves and monitoring times for other emissions sources, e.g. pumps, compressors etc. estimated by the Exxon Company and other studies. Table 5-1 compares the estimated and actual monitoring times for each of the 24 units in the EPA study. Overall, the actual time was about 75 percent of the estimated time. In another study conducted by Union Carbide Corporation in one of their chemical units it was estimated that 400-500 sources could be screened in one day.[3] Although this estimate is based on a three-man team, the third person is a unit operator to provide process data. Therefore, for a two-man monitoring team this corresponds to 1.9 - 2.4 man-minutes per source.

TABLE 5-1. ESTIMATED VERSUS ACTUAL MONITORING TIMES FOR SOCMI PROCESS UNITS IN THE 24 UNIT STUDY

Unit Number	Chemical	Total Number of Sources Monitored	EPA-Estimated Monitoring Time[a] (hours)	Actual Monitoring Time (hours)
1	Vinyl Acetate	1391	54	46
2	Ethylene	5078	176	110
3	Vinyl Acetate	2713	98	42
4	Ethylene	5278	182	132
5	Cumene	1025	36	15
6	Cumene	1573	55	26
11	Ethylene	3685	143	117
12	Acetone/Phenol	3207	128	171
20,21	Ethylene Dichloride/ Vinyl Chloride	2298	91	100
22	Formaldehyde	230	9	7
28,29	Ethylene Dichloride/ Vinyl Chloride	3363	123	90
31	Methyl Ethyl Ketone	585	22	16
32	Methyl Ethyl Ketone	679	26	25
33	Acetaldehyde	1148	44	23
34	Methyl Methacrylate	2019	77	30
35	Adipic Acid	1577	53	18
60,61,62	Chlorinated Ethanes	3332	121	89
64	Adipic Acid	664	26	21
65	Acrylonitrile	1406	51	59
66	Acrylonitrile	1864	68	59
TOTALS		43,115	1583	1196

[a] Estimated monitoring time is based on the equipment counts in each unit and the monitoring time estimates for each source presented in the BID.

Source: Reference 4.

Other data were provided by Phillips Petroleum Company. In a study conducted at a refinery and natural gas processing center which included three ethylene units, Phillips screened about 70,000 sources with a 2 man team in about 936 manhours for an average of 0.8 man-minutes per source.[5] A monitoring time estimate of 2 man-minutes per valve was used in the BID.

(2) Repair time: The California Air Resources Board conducted a study of fugitive emissions.[6] The repair time estimate of 10 man-minutes for on-line repair of valves was based on this study. The repair time estimate for off-line repair was 4 man-hours per valve and was based on the Exxon study.[7]

(3) Fraction of leaks repaired on-line and off-line: This estimate was also based on the California Air Resources Board Study.[8] 75 percent of all valves were estimated to be repaired on-line while 25 percent were estimated to be repaired off-line.

5.1.2 New Information

Allied Chemical Company conducted a study of fugitive emissions in a high density polyethylene unit.[9] A two-man team was used to conduct the screening. One man performed the screening while the other recorded the data. The unit, area, the tag number, and the screening value were recorded. All leaking sources were tagged. The overall monitoring time for six inspections averaged 2.9 man-minutes per source. However, by the sixth inspection the monitoring time was down to 1.9 man-minutes per source.

The on-line repair time requirement for valves was determined in six process units during the EPA maintenance study.[10] The repair time requirement determined in this study was 9.6 man-minutes. The summary of the maintenance study repair time data is presented in Table 5-2.

5.1.3 Public Comments

Three major comments were received regarding the cost estimates for valves.

1. Several commenters expressed disagreement with the monitoring time estimate. One commenter said that the monitoring time estimate was low by a minimum factor of two. Another commenter stated that the data provided by the industry had been used out of context to come up with the estimate. He

TABLE 5-2. SUMMARY OF ON-LINE REPAIR TIME DATA
(Six Unit Maintenance Study)

Unit	Maintenance Period	Number of Attempts	Total Time for Maintenance (minutes)	Average Maintenance Time Per Valve (minutes)
1	1	10	180	18.1
		3		N.A.
2	1	13	201	13.4
	2	8 (2)*	287	28.7
		2		15.0
		2		N.A.
3	1	8	48	6.0
		5 (2)*	45	6.3
		4	15	3.7
4	1	18	125	6.9
		10 (2)*	60	5.0
		10 (1)*	80	7.3
		8	143	17.9
5	1	3 (1)*	70	17.5
	2	29 (3)*	129	4.0
6	1	8 (6)*	90	6.4
	2	13	125	9.6
		1		N.A
Total		149**(17)*	1,598	9.6

*Valves were not maintained.

**Does not include valves for which no time information was available.

(N.A. - No information on time of maintenance available).

Source: Reference 11.

said that the 2 man-minutes figure was generated as a ball-park number for initial comparison purposes. Commenters claimed that more recent detailed data show monitoring times of 3 to 4 minutes. An industry report was cited which shows that the monitoring time varies from a minimum of 3 minutes to a maximum of 12 minutes per valve.

2. One commenter was concerned that the cost estimates did not include any unit downtime for repair of valves which must be taken off-line for repair.

3. Another commenter asked that further consideration of administrative manpower be made. As an example, he estimated that a unit with 2,800 valves would require about 15 to 20 man-days of engineering time and 250 to 300 man-days of drafting time to establish the program. He said that added to this would be drafting time for showing minor revisions in the plant or monitoring schematics.

5.1.4 EPA's Conclusions

The estimate used for monitoring time was based on information provided by Exxon Company, USA. This information was presented as the result of "an in-depth study to determine the monitoring manpower requirements."[12] In absence of data to the contrary, a monitoring time of 2 man-minutes is the most reasonable estimate available. In addition, information from other studies shows that the monitoring time may even be less than 2 man-minutes. It should be noted that valves are expected to be clustered in groups. It would be possible to monitor one group in a short time and then move on to another. The 2 man-minutes estimate is an average for all valves in a unit. The 3 to 12 man-minutes estimate made in a document cited in the public comments was inaccurately cited as a monitoring time estimate for valves. These are actually estimates of time required to monitor pump seals, compressor seals, valves, drains, and pressure relief valves. Furthermore, these estimates also include time required for doing some minor valve repair. The repair time requirement was accounted for separately in the BID. It should be noted that the repair time requirement determined by the maintenance study i.e. 9.6 man-minutes has verified the 10 man-minutes estimate used in the BID.

There would be no need for a unit to shut down for repair. Allowance is made for repairing such critical valves at the next unit turnaround. Because shutdowns are not required, allowance for cost of unit downtime is not necessary.

The engineering and draft time requirement mentioned by one commenter was accounted for in the BID. The labor charge estimates used in the BID include allowance for administrative and support costs to implement the regulation. The details of these estimates are discussed later in Section 5.7 (Other Costs).

Based on the results of the LDAR Model[13] (discussed in Section 4) the annual cost of monitoring and repair of valves have been estimated for the following monitoring intervals: (1) monthly, (2) quarterly, (3) quarterly with monthly follow-up of leaking valves, (4) semi-annual, and (5) annual. An example cost calculation (for monthly monitoring) is presented in Tables 5-3 through 5-6 for model units A, B, and C (see Section 3 on Model Units). The input parameters e.g. occurrence rate, initial leak frequency, etc. are discussed in the Emission Reduction section (Section 4).

A similar procedure is followed to calculate the net annualized costs of monthly/quarterly, quarterly, semi-annual, and annual leak detection and repair programs for valves. These costs are summarized in Table 5-7.

The costs shown are for the second turnaround period. The second turnaround period (the time between turnarounds 1 and 2) was used to minimize the uncertainties in determining when in the first turnaround cycle the leak detection and repair program began. Furthermore, the second turnaround period average approximates the average for turnaround periods after a leak detection and repair program has been in place for a long time.

5.2 PUMPS

5.2.1 Technical Basis in the BID

The costs for both equipment control and leak detection and repair programs were calculated in the Background Information Document. These costs are presented below.

TABLE 5-3. INITIAL LEAK REPAIR LABOR-HOURS REQUIREMENT FOR VALVES BY MODEL UNIT

No. of Valves Per Model Unit			Initial Leak Frequency	Estimated No. of Initial Leaks			Repair Time, Man-Hours[a]	Labor-Hours Required		
A	B	C		A	B	C		A	B	C
99	402	1232(G)	0.114	11.3	45.8	140.4	1.13	12.8	51.8	158.7
131	524	1618(LL)	0.065	8.5	34.1	105.2	1.13	9.6	38.5	118.9
								22.4	90.3	277.6

[a] Based on 75 percent valves repaired on-line in 10 man-minutes and 25 percent repaired off-line in 4 man-hours.

TABLE 5-4. TOTAL COSTS FOR INITIAL LEAK REPAIR FOR VALVES BY MODEL UNIT

	A	B	C
Initial Leak Repair Labor Charges ($15/hour)	$336	1355	4164
Admin. & Support Costs (0.4 x labor charges)	134	542	1666
Total Costs	$470	1897	5830
Annualized charges for initial leak repair (0.163 x total costs)[a]	$77	309	950

[a] Initial leak repair costs amortized over 10 years at 10 percent interest (CRF = 0.163).

TABLE 5-5. ANNUAL MONITORING AND LEAK REPAIR LABOR REQUIREMENTS
(Monthly Leak Detection and Repair Program for Valves)

No. of Valves Per Model Unit			Type of Monitoring	Monitoring Time, Man-Min[a]	Times Monitored Per Year	Monitoring labor-hours Required			No. of leaks Per Year[b]			Repair Time, Man-hours	Leak Repair Labor-hours Required		
A	B	C				A	B	C	A	B	C		A	B	C
99	402	1232(G)	Instrument	2	12	39.6	160.8	492.8	18.9	76.8	235.3	1.13	21.4	86.8	265.9
131	524	1618(LL)	Instrument	2	12	52.4	209.6	647.2	25.0	99.9	308.4	1.13	28.3	112.9	348.5
						92.0	370.4	1140.0					49.7	299.7	614.4

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[a] Instrument monitoring time is 1 minute for a 2 man team.

[b] Average number of leaks found over turnaround 2 from the LDRP model, based on monthly occurrence rate of 1.3 percent.

TABLE 5-6. ANNUAL MONITORING AND LEAK REPAIR COSTS FOR MONTHLY MONITORING OF VALVES BY MODEL UNIT

	A	B	C
Monitoring labor-hours	92.0	370.4	1140.0
Repair labor-hours	49.7	199.7	614.4
Total labor-hours (Monitoring & Repair)	141.7	570.1	1754.4
Labor charges ($15 x total labor-hours)	$2126	8552	26316
Admin. & Support costs (0.4 x labor charges)	850	3421	10526
Annualized charge for initial leak repair	77	309	950
Total costs ($/year)	$3043	12282	37792
Product recovery credit[a] ($/year)	(2490)	(9990)	(31020)
Net annualized costs ($/year)	$553	2292	6772

[a] Product recovery credit is calculated at $300/Mg. The emission reductions are shown in Section 4.

Note: Figures in parenthesis indicate credits.

TABLE 5-7. NET ANNUAL MONITORING AND REPAIR COSTS OF LEAK DETECTION AND REPAIR PROGRAMS FOR VALVES BY MODEL UNITS

Monitoring Interval	Net Annualized Costs A	 B	 C
Monthly	550	2300	6800
Monthly/Quarterly	(290)	(1060)	(3300)
Quarterly	(270)	(1050)	(3200)
Semi-annual	140	450	1400
Annual	1300	5100	15600

Note: Figures in parenthesis indicate a credit.

Equipment Costs: The equipment for pumps consisted of the following. (1) Dual mechanical seals, (2) barrier fluid systems for dual mechanical seals, and (3) closed vents for degassing reservoirs of dual seal pumps. The cost estimates are in last quarter 1978 dollars and were based on data from the Hydroscience (now ITE) report.[14] The cost items are as follows:

Dual Mechanical Seals	$575/pump	[Seal cost = $560. Single seal credit = $225. Shop installation = $240.]
Barrier fluid system for dual seals	$1500/pump	[Pressurized reservoir system = $700. System cooler = $800. Pumps that have dual mechanical seals without regulatory requirement may not have the cost of a barrier fluid system added. The barrier fluid system is assumed to be an integral part of the seal system.]
Closed vents for degassing reservoirs	$3265/pump	[Based on installation of a 122m length of 5.1 cm. diameter, schedule 40 carbon steel pipe = $5200. Three 5.1 cm. cast steel plug valves and one metal gauze flame arrestor = $1300. These costs include connection of the degassing reservoir to an existing enclosed combustion device or vapor recovery header. Cost of a control device added specifically to control the degassing vents is, therefore, not included. Two pumps assumed connected to a single degassing vent.]
Total Cost (last quarter 1978 dollars)	$5340/pump	

Leak Detection and Repair Costs: The factors affecting the costs of a leak detection and repair program are (1) monitoring time and (2) repair time. Both these estimates were based on information provided by Exxon Company, USA.[15] These estimates were (1) 10 man-minutes for instrument monitoring, (2) 0.5 man-minutes for visual monitoring, and (3) 80 man-hours for repair [based on 2 man-days/pump for field repair (25 percent) and 12.5 man-days/pump for shop repair (75 percent)].

5.2.2 New Information

No new information was developed regarding cost estimates for pumps.

5.2.3 Public Comments

Comments were received on the equipment cost estimates, on the costs associated with a control device, and retrofit costs.

1. One commenter gave estimates of $3900 and $7000 per pump for equipment cost estimates. The BID estimate was said to be lacking in costs of three components: a spare flushing oil pump, strainers, and instrumentation. The average cost of a dual seal was said to be $1250 (1980 dollars).

2. Several commenters said that even though a control device may already exist at a facility, it cannot be considered a cost-free utility. Such equipment was said to be a major portion of the total capital investment for implementation of the proposed rules. The commenters asked that the cost of the control device be included in the analysis.

3. One commenter said that equipment layout considerations had been ignored and that the cost of real estate or adequate transmission lines had not been included.

4. Two commenters said that energy costs associated with enclosed combustion devices had not been included in the cost estimates. One of the commenters also said that another energy cost which had been overlooked was energy required for a high pressure barrier fluid system.

5. There was also some concern that retrofit costs had been underestimated. For example, it was said that an existing plant may not have enough room for installing a barrier fluid degassing system and combustion device close to the pump. Locating the equipment away from the pump will increase construction and operating costs by requiring more piping and increasing the energy requirements for the system.

6. One commenter said that labor costs for replacement items such as pump seals would be higher than the cost for initial installation. The reason for this was said to be the higher time requirement for disassembly of equipment and the inefficiencies of working in the field.

5.2.4 EPA's Conclusions

The cost of the barrier fluid system includes the costs for the components considered lacking by the commenters. However, the cost of the dual seal has been revised to reflect the estimate provided by the commenters. In 1978 dollars the installed cost of a dual seal (after credit for the single seal) is estimated to be $1030. The BID estimate of this cost was $575.

No need was seen for the addition of the cost of an enclosed combustion device. The cost to a facility due to a regulation is the incremental expenses incurred in order to comply with the regulation. Combustion devices or vapor recovery systems are expected to already exist at the plant site. There will, therefore, be no incremental cost associated with the use of the device. The capital cost of such an existing device need not be accounted for in the cost analysis. Transmission lines have also been adequately accounted for. The cost of the degassing reservoir vents includes 122m of piping. The real estate will be available at the site.

As discussed in Section 7.4 of the BID there are no energy costs associated with the proposed standards. In fact, the use of combustion devices could result in a net energy credit if heat energy is recovered. However, since it is not possible to quantify the number of process units that may choose to recover heat or the extent of the recovered energy, these credits were ignored for the purpose of the cost analysis. The equipment for pumps includes a low pressure barrier fluid system. There is, therefore, no cost for the energy requirements of a high pressure barrier fluid system. If a high pressure barrier fluid system were used, there would be no need for the degassing vent piping.

Shortage of space at an existing plant may make it difficult to install a barrier fluid system and combustion device close to the pump. However, in such cases it is expected that most units would choose to enclose seal areas and vent the captured emission to an existing control device. Only piping and a block or check valve would then be required.

As shown in Section 5.2.1, the initial cost of installation of pump seals is based on labor requirements for replacing an old seal. As such, instead of replacement cost being understated, the initial installation costs are overstated.

Section 4 (Emission Reductions) presented the comments made by the industry regarding use of flares for control of emissions from pumps and compressors. An analysis of costs for a dual seal/barrier fluid system vented to a flare has been performed for the purpose of comparison with costs of a dual seal system vented to an enclosed combustion device or a vapor recovery system. In addition, leak detection and repair costs have been recalculated with some changes in estimates. The details of these analyses are presented below.

Equipment Costs: Two control levels were identified in order to provide a range of control costs:

(1) Dual pump seal/barrier fluid systems provide no fugitive VOC emission reduction;

(2) Dual pump seal/barrier fluid systems provide 95 percent reduction of fugitive VOC emissions.

For the purpose of this cost analysis, it was assumed that existing flares achieve 90 percent control while enclosed combustion devices (including devices such as condensers, absorbers, adsorbers, etc.) achieve 95 percent control. As discussed earlier, no heat recovery credit is given for VOC controlled by enclosed combustion devices since the credit is hard to account for, is generally small, and may be intermittent.

Capital costs of a VOC emissions control system for a pump seal include the costs of dual seals, a barrier fluid system, and a degassing vent system. The costs of the flare or the enclosed combustion device are not included as they are assumed to be available at the plant site. Further, the cost of a vent system servicing an enclosed combustion device is much greater than the cost of a vent system servicing a flare because a flame arrestor and additional piping and valves are required. Enclosed combustion devices do not have existing common duct systems (header) in the process unit to which fugitive emissions may be vented. Therefore, individual piping systems are provided to vent the VOC to the enclosed combustion device. To avoid flame propagation from the combustion device to the degassing reservior, each line is equipped with a flame arrestor. To allow in-service repair of the flame arrestor, each arrestor assembly is outfitted with a bypass system of piping and valves. Usually, a flare header runs throughout a process unit to collect gases from minor process vents and pressure relief devices. Therefore, only short lengths of piping would be needed to connect the degassing reservoir to the flare system. Each pipe that is connected to the flare header is equipped with a check valve to avoid back pressure into the degassing reservoir. A block valve for isolating the degassing reservoir from the flare system is also provided to allow positive shutoff from the flare header during seal maintenance. The cost analysis is presented in Tables 5-8 and 5-9.

Leak Detection and Repair Costs: Leak detection and repair costs have been recalculated to reflect some changes in estimates. Changes were made in the estimate of repair time. The monitoring time estimate remains the same.

In the BID, a repair time estimate of 80 man-hours per pump seal was used. This estimate was based on information provided by Exxon Company, USA.[16] It was assumed that 25 percent of the pumps would be repaired in the field at the rate of 2 man-days/pump and 75 percent would be repaired in the shop at the rate of 12.5 man-days/pump.

Further consideration of these estimates indicates that shop repair would only be needed for cases where the problem is related directly to the pump itself. Field repair would be sufficient for the purpose of seal replacement. The repair time estimate has, therefore, been changed to 16 man-hours per pump. In addition, the cost of the replacement seal was not included in the total cost of repair in the BID. This cost has now been included in the analysis of leak detection and repair costs. The credit for the old seal is estimated to be half the purchase price of the new seal.[17]

Finally, it is assumed that the life of a pump seal, is 2 years.[18] Therefore, 1/24 (4.2 percent) of all pump seals will be replaced as routine

TABLE 5-8. EQUIPMENT COST FOR CONTROL OF EMISSIONS FROM A PUMP SEAL (last quarter 1978 dollars)

	Degassing Reservoir Vented to a Flare	Degassing Reservior Vented to an Enclosed Combustion Device
Capital Costs		
Dual seal[a]	1030	1030
Barrier fluid[b]	1500	1500
Vent system	700[c]	3265[b]
Total	3230	5795
Annual Costs		
Dual seal[d]	500	500
Barrier fluid[e]	245	245
Vent system[e]	115	530
Maintenance & Miscellaneous charges[f]	250	480
Total[g]	1110	1755

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[a] Based on $1250/seal (1980 dollars) average cost quoted by industry. 1978 cost = $1030 (seal cost = $1015, installation cost = $240, single seal credit = $225).

[b] From Chapter 8 of the BID.

[c] Based on installed capital cost of 20m of 5.1cm piping ($850), one 5.1cm check valve ($125), and one 5.1cm block valve ($415) per vent system and one vent per pair of pump seals.

[d] Based on 2 year seal life and 10 percent interest (CRF = 0.58) for dual seal and 10 year amortization period and 10 percent interest (CRF = 0.163) for installation charges.

[e] Based on 10 year equipment life and 10 percent interest (CRF = 0.163).

[f] Based on 9 percent of total capital costs (Chapter 8 of the BID).

[g] Costs do not include credits for recovered product.

TABLE 5-9. NET ANNUALIZED COST OF EQUIPMENT FOR CONTROL OF EMISSIONS FROM PUMP SEALS (last quarter 1978 dollars)

	Degassing Reservoir Vented To a Flare		Degassing Reservoir Vented To an Enclosed Combustion Device	
	(1) 95 Percent Control by Seal	(2) No Control by Seal	(1) 95 Percent Control by Seal	(2) No Control by Seal
Gross annualized cost ($/year)	$1110	1110	1755	1755
Product recovery credit ($/year)	(123)[a]	0	(123)[a]	0
Net annualized cost ($/year)	987	1110	1632	1755

[a] Credit from 95 percent of uncontrolled VOC fugitive emissions that are retained in the process due to operation of a pressure sensor between the dual seals to immediately detect seal failure. Product valued at $300/Mg.

Note: Columns (1) and (2) show a range of net annualized costs depending upon the degree of control by the seal.

maintenance every month. On the average, half of routinely maintained seals, i.e. 2.1 percent of all seals are assumed to be leaking seals. No cost is attributed to the program for the leaking seals that will be replaced due to routine maintenance.

Leak detection and repair costs have been calculated for monthly, quarterly, semi-annual, and annual programs for pumps. An example calculation (for monthly monitoring program) is presented in Tables 5-10 through 5-14 for model units A, B, and C (see Section 3 on Model Units). The input parameters e.g. occurrence rate, initial frequency, etc. are discussed in the Emission Reduction section (Section 4).

A similar procedure is followed to calculate costs of quarterly, semi-annual, and annual leak detection and repair programs for pumps. These costs are summarized in Table 5-14.

5.3 SAFETY/RELIEF VALVES

5.3.1 Technical Basis in the BID

Cost of control of fugitive emissions from safety/relief valves were calculated for both leak detection and repair programs and equipment control.

Leak Detection and Repair Costs: Costs were calculated for quarterly and monthly monitoring of gas service safety/relief valves. The monitoring time estimate was based on information provided by Exxon Company.[19] This estimate was 16 man-minutes. Also, as suggested by Exxon, it was assumed that leaks would be corrected by routine maintenance with no additional labor requirements.

Equipment Costs: Costs were computed for the installation of a rupture disk upstream of a safety/relief valve in gas service. These costs were based on estimates from the Hydroscience (now IT Environscience)[20] report. The cost estimates were for the following items.

One 7.6cm stainless steel rupture disk	$195
One 7.6cm carbon steel rupture disk holder	325
One 0.6cm dial face pressure gauge	15
One 0.6cm carbon steel bleed valve	25
Installation	240
Subtotal	$800

TABLE 5-10. INITIAL LEAK REPAIR LABOR-HOURS REQUIREMENT FOR PUMP SEALS BY MODEL UNIT

No. of Pump Seals Per Model Unit			Initial Leak Frequency	Estimated No. of Initial Leaks			Repair Time, Man-hours	Labor-hours Required		
A	B	C		A	B	C		A	B	C
8	29	91	0.088	0.7	2.6	8	16	11.2	41.6	128

TABLE 5-11. TOTAL COSTS FOR INITIAL LEAK REPAIR FOR PUMP SEALS BY MODEL UNIT

	A	B	C
Initial Leak Repair Labor Charges ($15/hour)	$168	624	1920
Admin. & Support Costs (0.4 x labor charges)	67	250	768
Seal Costs ($113/single seal)[a]	79	293	900
Total Costs	$314	1167	3588
Annualized charges for initial leak repair (0.163 x Total costs)[b]	51	190	585

[a] Includes 50 percent credit for old seal.

[b] Initial leak repair costs amortized over 10 year at 10 percent interest (CRF = 0.163).

TABLE 5-12. ANNUAL MONITORING AND LEAK REPAIR LABOR REQUIREMENTS
(Monthly Leak Detection and Repair Program for Pump Seals)

No. of Pumps Seals Per Model Unit			Type of Monitoring	Monitoring Time Man-Min[a]	Times Monitored Per Year	Monitoring labor-hours Required			No. of leaks Per Year[b]			Repair Time, Man-hours	Leak Repair labor-hours Required		
A	B	C				A	B	C	A	B	C		A	B	C
8	29	91	Instrument	10	12	16.0	58.0	182.0	3.3	11.8	37.1	16	52.8	188.8	593.6
			Visual	0.5	52	3.5	12.5	39.4							
						19.5	70.5	221.4							

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[a] Instrument monitoring time is 5 minutes for a two-man team.

[b] Based on 5.5 percent monthly occurrence rate less 2.1 percent credit for routine maintenance. These values were computed using the LDAR model. Fractions of leaking pumps were included in both cost and emission estimates.

TABLE 5-13. ANNUAL MONITORING AND LEAK REPAIR COSTS FOR PUMP SEALS BY MODEL UNIT

	A	B	C
Monitoring labor-hours	19.5	70.5	221.4
Repair labor-hours	52.8	188.8	593.6
Total labor-hours (Monitoring & Repair)	72.3	259.3	815.0
Labor charges ($15 x total labor-hours)	$1085	3890	12225
Admin. & Support costs (0.4 x labor charges)	434	1556	4890
Annualized charge for initial leak repair	51	190	585
Seal costs ($113/seal)[a]	372	1328	4174
Total costs ($/year)	$1942	6964	21874
Product recovery credit[b] ($/year)	(632)	(2290)	(7183)
Net annualized cost ($/year)	$1310	4674	14691

[a] Includes 50 percent credit for old seal.

[b] Product recovery credit is calculated at $300/Mg. The emission reductions are shown in Section 4.

Note: Figures in parentheses indicate a credit.

TABLE 5-14. NET ANNUAL MONITORING AND REPAIR COSTS OF LEAK DETECTION AND REPAIR PROGRAMS FOR PUMP SEALS BY MODEL UNIT

Monitoring Interval	Net Annualized Costs A	B	C
Monthly	$1300	4700	15000
Quarterly	1300	4800	15000
Semi-annual	1600	5800	18000
Annual	2200	8000	26000

It was assumed that no piping modification was required and that the disk and its holder simply could be inserted between the flanges of the relief valve and the system it protects. To allow in-service disk replacement, a block valve was assumed to be installed upstream of the rupture disk. In addition, to prevent damage to the relief valve by disk fragments, it was assumed that an off-set mounting would be required. The total installed cost of a new rupture disk system was estimated to be $1730 (last quarter 1978 dollars). The rupture disk life was assumed to be 2 years.

5.3.2 New Information

No new information was developed regarding cost estimates for safety relief valves.

5.3.3 Public Comments

Several comments were received on the relief valve/rupture disk cost estimates.

1. One commenter said that the cost of repair and monitoring of relief valve/rupture disk systems should be included in the analysis. He estimated that it would take 10 minutes to monitor the relief valve after repair. The cost of the replacement disk would be $200. Four hours were estimated for repair. He further estimated 3 discharges per year.
2. Another commenter said that the capital cost of the relief valve/rupture disk systems had been underestimated. He cited assumption of very modest piping modification to be the reason for the low cost estimate. His estimates were $3800 per disk for a new installation including disk, flanges, a tee downstream, and a pressure gauge.
3. On the other hand, another commenter said that the capital cost for relief valves/rupture disk systems have been overstated. He said that new developments have eliminated the requirement for offset monitoring and the cost of tees, elbows, etc. have been eliminated.

5.3.4 EPA's Conclusions

As pointed out by one commenter, some relief valves may have 3 discharges per year. On the other hand, according to information from Exxon Company, USA, "most safety valves on light ends towers never discharge."[21] On the average, a rupture disk may be expected to require replacement every

2 years. This estimate of useful life is assumed in the cost analysis, i.e. an allowance for replacement of the rupture disk every 2 years has been made in the analysis.

Equipment cost estimates for control of fugitive emissions from safety/relief valves have been calculated for four different systems. It is expected that each of the four systems would be used for a certain proportion of relief valves in the industry. These costs are shown in Table 5-15.

5.4 SAMPLING SYSTEMS

5.4.1 Technical Basis in the BID

Equipment costs were computed for closed loop sampling connections. The cost estimates were based on information from the Hydroscience (now ITE) report[24] and are shown in Table 5-16.

5.4.2 New Information

The Texas Chemical Council (TCC) has estimated that 75 percent of the sampling systems in new plants are currently closed loop sampling systems.[25]

5.4.3 Public Comments

Carbon steel construction was said to be inadequate for many sampling applications in SOCMI. The cost of a stainless steel closed loop sampling connection was said to be $1600.

5.4.4 EPA's Conclusions

EPA has seen no evidence that carbon steel construction may not be adequate for most sampling applications in SOCMI. In addition, since 75 percent of the sampling systems in new plants are closed loop type the cost estimates in the BID have overstated the cost of regulation to the industry. EPA expects that the 75 percent of the sampling systems which are closed purge systems are in toxic or corrosive service which might require stainless steel. EPA further believes that the remaining 25 percent can use carbon steel materials.

To reflect the new information concerning the number of closed loop sampling systems currently in use, a change has been made in the uncontrolled equipment count for model units. For details see Section 3 on Model Units.

TABLE 5-15. RELIEF VALVE CONTROL COSTS, FOUR SYSTEMS

(1)	Rupture disk systems with block valves	Total Capital Cost = $1730/relief valve (Details presented earlier)
		Annualized Costs
	Rupture disk[a]	$112
	Holders, etc.[b]	250
	Maintenance & Misc.[c]	156
	Total ($/year)	$519
(2)	Rupture disk systems with 3-way valve.[22]	
	Assembly	
	One 7.6cm stainless steel rupture disk	$195
	One 7.6cm carbon steel disk holder	325
	One 0.6cm dial face pressure gauge	15
	One 7.6cm safety/relief valve	1240
	Two 7.5cm elbows	25
	Subtotal	$1825
	Three-way Valve	
	One 7.6cm, 3-way, 2 port valve	1120
	Installation	540
	Subtotal	$1660
	Total Cost (last quarter 1978 dollars)	$3485
		Annualized Costs
	Rupture disk[d]	$113
	Holder, valve, etc.[e]	536
	Maintenance & Misc.[f]	314
	Total ($/year)	$963
(3)	O-rings	Total Costs = $200/relief valve (last quarter 1978 dollars)
		Annualized Costs
	O-ring[g]	$33
	Maintenance & Misc.[h]	18
	Total ($/year)	$51

TABLE 15. (CONTINUED)

(4) Closed vent system to transport the discharge or leakage of safety/relief valves to a flare.	$1960/relief valve [Based on installation of 15m of 10.2cm diameter schedule 40 carbon steel pipe. Cost (1967) = $700. Cost index = 278.1/113. Installation = $60. One 10.1cm carbon steel check valve = $180.][23]

	Annualized Costs
Vent System[i]	$320
Maintenance & Misc.[j]	176
Total ($/year)	$496

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[a] Based on 2 year equipment life and 10 percent interest (CRF = 0.58).

[b] Based on 10 year equipment life and 10 percent interest (CRF = 0.163).

[c] Based on 9 percent of total capital costs.

[d] Based on 2 year equipment life and 10 percent interest (CRF = 0.58).

[e] Based on 10 year equipment life and 10 percent interest (CRF = 0.163).

[f] Based on 9 percent of total capital costs.

[g] Based on 10 year equipment life and 10 percent interest (CRF = 0.163).

[h] Based on 9 percent of total capital cost.

[i] Based on 10 year equipment life and 10 percent interest (CRF = 0.163).

[j] Based on 9 percent of total capital cost.

TABLE 5-16. COSTS FOR CLOSED LOOP SAMPLING SYSTEMS

One 6m length of 2.5cm diameter schedule 40, carbon steel pipe and three 2.5cm carbon steel ball valves.	$190
Installation	270
Total/sampling connection (last quarter 1978 dollars)	$460
	Annualized Costs
Closed Loop Connection[a]	$75
Maintenance & Misc.[b]	41
Total ($/year)	$116

[a] Based on 10 year equipment life and 10 percent interest (CFR = 0.163).

[b] Based on 9 percent of total capital cost.

5.5 OPEN-ENDED LINES

5.5.1 Technical Basis in the BID

Equipment costs were calculated for caps on open-ended lines. The estimate was based on information in the text "Plant Design and Economics for Chemical Engineers".[26] The costs are shown in Table 5-17.

5.5.2 New Information

The Texas Chemical Council (TCC) has estimated that all open-ended lines in new units are already capped as routine procedure.[27]

5.5.3 Public Comments

One commenter disagreed with the cost estimates for caps for open-ended lines. He felt that an average size of 3.8cm to 5cm (1.5in. to 2in.) was more realistic than the 2.5cm estimate in the BID. The commenter estimated an average cost for screwed valves of $150 each. He further stated that many small lines are constructed of stainless steel instead of carbon steel. Also, many lines, he said, 2.5cm or larger, are flanged, not screwed.

5.5.4 EPA's Conclusions

Information obtained from the Hydroscience (now ITE) study[28] shows that 92 percent of open-ended lines are 5cm. or less in diameter.[29] Based on this information, the 2.5cm. estimate for the average valve size seems reasonable. Larger lines would be expected to use blind flanges which cost about the same as small valves.

As in the case of sampling systems, the equipment count for model units has been corrected to reflect the new information regarding the current practice of capping open-ended lines in SOCMI units. The corrections are discussed in Section 3 on Model Units.

5.6 COMPRESSORS

5.6.1 Technical Basis in the BID

The costs for both equipment control and leak detection programs were calculated in the BID. These costs are presented below.

Equipment Costs: The cost of control equipment for compressors was based on installation of closed vents for degassing reservoirs of compressors. The estimate was based on information contained in the Hydroscience (now ITE) report[30] and was for the following items:

TABLE 5-17. COSTS FOR AN OPEN-ENDED LINE CAP

One 2.5cm screwed valve	$30
Installation	15
Total (last quarter 1978 dollars)	$45
	Annualized Costs
Caps for Open-Ended Lines[a]	$7
Maintenance & Misc.[b]	4
Total ($/year)	$11

[a] Based on 10 year equipment life and 10 percent interest (CRF = 0.163).

[b] Based on 9 percent of total capital cost.

122m length of 5.1cm diameter, schedule 40 carbon steel pipe	$5200
Three 5.1cm cast steel plug valves and one metal gauze flame arrestor	1330
Total (last quarter 1978 dollars)	$6530/compressor

The above costs include connection of the degassing reservoir to an existing enclosed combustion device or vapor recovery header. Cost of a control device added specifically to control the degassing vents, is therefore, not included.

Leak Detection and Repair Costs: The factors affecting the costs of a leak detection and repair program are monitoring time and repair time. Both these estimates were based on information provided by Exxon Company, USA.[31] The estimates were (1) 20 man-minutes for monitoring time and (2) 40 man-hours for repair time.

5.6.2 New Information

No new information was received regarding cost estimates for compressors.

5.6.3 Public Comments

As with pumps, concern was expressed about the cost of existing control device not being included in the analysis. Commenters said that even though a control device may exist at a facility, it cannot be considered a cost-free utility. Each user, therefore, should assume a share of the capital and operating costs of the device.

5.6.4 EPA's Conclusions

As discussed in the section on pumps, no need is seen for the addition of the cost of an existing combustion device since it is not an incremental cost due to the regulation.

Also, as in the analysis for pumps, costs have been calculated for degassing reservoir of compressors vented to flares as well as enclosed combustion devices. These costs are presented below.

Equipment Costs: Two control levels are identified in order to provide a range of control costs:

(1) Compressor seals provide no fugitive VOC emissions reduction;

(2) Compressor seals provide 95 percent reduction of fugitive VOC emissions. For the purpose of this cost analysis, it was assumed that existing flares achieve 90 percent control while enclosed combustion devices (including condensers, absorbers, etc.) achieve 95 percent control. No heat recovery credit is given for VOC controlled by enclosed combustion device (as discussed in Section 5.2.4 on Pumps). The cost analysis for compressors is presented in Tables 5-18 and 5-19. The reasons for the difference in the costs for flares and enclosed combustion devices were also previously discussed in Section 5.2.4 on pumps.

The cost estimates presented in Tables 5-18 and 5-19 are for control of an uncontrolled compressor seal; they should not be applied directly to the model unit or the industry compressor population. As discussed in Section 3, 60 percent of the compressors in the industry are assumed to be controlled currently by effective systems. Therefore, in estimating costs of controlling compressor seals on a model unit basis, and extrapolating to the industry, 40 percent of the costs listed in these tables are applied to the compressor seal counts for each model unit.

Leak Detection and Repair Costs: The costs of monthly and quarterly leak detection and repair programs for compressors were presented in the BID. No further calculations of costs for leak detection and programs for compressors were performed. Further analysis seemed unnecessary for two major reasons. First, a large percentage of the compressors tested in SOCMI had control equipment installed. Second, if a compressors were found leaking at 10,000 ppm, the expected repair technique would be the installation of control equipment. Furthermore, since compressors are not generally spared, repair to a non-leaking status would have to be postponed until the next turnaround, thereby eliminating almost completely the effectiveness of the leak detection and repair program.

5.7 OTHERS

5.7.1 Technical Basis in the BID

The estimates of other input cost parameters used in the BID are presented below.

TABLE 5-18. EQUIPMENT COST FOR CONTROL OF EMISSIONS FROM COMPRESSOR SEALS (last quarter 1978 dollars)

	Degassing Reservoir Vented to a Flare	Degassing Reservoir Vented to an Enclosed Combustion Device
Capital Costs		
Vent System	1400[a]	6530[b]
Annual Costs		
Vent System[c]	230	1060
Maintenance & Miscellaneous charges[d]	130	590
Total[e]	360	1650

[a] Based on installed capital cost of 20m of 5.1cm piping ($860), one 5.1cm check valve ($125), and one 5.1cm block valve ($405) per unit system and one vent per compressor seal.

[b] From Chapter 8 of the BID.

[c] Based on 10 year equipment life and 10 percent interest (CRF = 0.163).

[d] Based on 9 percent of total capital costs (Chapter 8 of the BID).

[e] Costs do not include credits for recovered product.

TABLE 5-19. NET ANNUALIZED COST OF EQUIPMENT FOR CONTROL OF EMISSIONS FROM A COMPRESSOR SEAL (last quarter 1978 dollars)

	Degassing Reservoir Vented to a Flare		Degassing Reservoir Vented to an Enclosed Combustion Device	
	(1) 95% Control by Seal	(2) No Control by Seal	(1) 95% Control by Seal	(2) No Control by Seal
Gross annualized cost ($/year)	$360	360	1650	1650
Product recovery credit ($/year)	(1395)[a]	0	(1395)[a]	0
Net annualized cost ($/year)	(1035)	360	(255)	1650

[a] Credit from 95 percent of uncontrolled fugitive VOC emissions that are retained in the process due to operation of a pressure sensor between the dual seals to immediately detect seal failure. Product recovery credit is based on emissions from one uncontrolled compressor. Emissions from uncontrolled compressor = 0.57 kg/hr. The composition of this emission factor was discussed in Section 3 (Model Units). Product valued at $300/Mg.

Note: Columns (1) and (2) show a range of net annualized costs depending upon the degree of control by the seal.

1. An hourly labor rate of $15 was used for 1978. This estimate included wages plus 40 percent of wages for labor-related administrative and overhead costs. These estimates were based on information presented in the control technique guidelines (CTG) for Petroleum Refineries.[32]

2. Administrative and support costs to implement the regulation were estimated to be 40 percent of monitoring and maintenance labor. This estimate was also based on the Refinery CTG.[33]

3. Two monitoring instruments per model unit were assumed to be required at a cost of $4250 per instrument. In addition, an annual maintenance cost of $2700 was assumed for the monitoring instruments. These estimates were provided by Century Systems[34] and the Refinery CTG.[35]

4. The product recovery credit was estimated to be $360 per Mg. The credit estimate was based on the average price of all SOCMI chemicals and was based on information obtained from the U.S. International Trade Commission[36].

5.7.2 New Information

No new information has been received regarding the above estimates.

5.7.3 Public Comments

1. Some commenters felt that labor costs had been underestimated. One commenter said that the labor charge should be $18 per hour. This estimate was said to be more representative of the Texas Gulf Coast experience. The commenter cited the recent wage settlements including employee benefits improvements in support of his arguments. Another commenter, while agreeing that $15 per hour was quite accurate as a base labor rate, expressed concern that overhead costs, labor benefits, social security taxes, and vacations had not been included. He estimated that the resulting loaded labor cost would be $25 per hour.

2. Disagreement was also expressed with the estimates of monitoring instruments costs. One commenter verified the cost of the instruments by contacting the manufacturer, but disagreed with the estimate of the number of instruments which would be required. He felt that one instrument for 1200 monitoring points with one for a spare was a good estimate. But he estimated that a large model unit with over 3000 points to monitor would

require four instruments, thereby doubling EPA's cost estimate for the large units.

3. Another commenter was concerned that the cost of instrument calibration and maintenance had not been considered. Looking at EPA contractor data for SOCMI plants, he said that about 20 percent of the total time expended by a contractor crew was devoted to instrument calibration and maintenance.

4. Finally, one commenter said that the product recovery credit was overstated. He estimated $220 per Mg instead of $360 per Mg. The commenter said that the average market value of $360 was based on very pure finished products. Emissions reduction will occur on new materials and semi-finished streams which have a lower product value.

5.7.4 EPA's Conclusions

Considering the fact that all BID estimates are in 1978 dollars, EPA feels that $15 per hour for labor costs is adequate. Also, it is not likely that the monitoring and maintenance team would be at the upper end of the industry wage scale. For workers at the lower end of the wage scale the estimate probably overstates the labor cost. It should also be noted that the $15 estimate includes allowance for overhead and administrative costs equal to 40 percent of the wages. Based on a review of the wage information for 1978, $11 per hour for direct wages and $4 per hour for overhead and administrative costs seems quite reasonable.

Even the most complex facilities are not expected to need more than two monitoring instruments. For example, the largest number of valves expected in a facility would be about 6,000. This means that for such a facility a maximum of 6,000 valves would be monitored during a given month. At the rate of 1 minute monitoring time per valve it will take 100 hours to monitor all 6,000 valves. This corresponds to 2 1/2 work weeks. Two monitoring instruments, therefore, will be sufficient.

As shown in Chapter 8 of the BID an allowance has been made for material and labor for monitoring instrument calibration and maintenance. This allowance is equal to $2700 per year. In addition, as discussed in Section 5.1.1 for valves, actual field tests in the 24 unit study have shown that the present monitoring time estimates include sufficient time for instrument calibration and maintenance.

The average product value used in the cost analysis is based on an average of costs for all SOCMI chemicals (including raw materials and finished products), weighted by the corresponding production volume of that chemical. Thus, the higher volume chemicals, which are generally the lower value chemicals, have the heaviest impact on the average product value. On the average, though, this estimate should closely reflect the value of products saved by emissions reduction because, if chemicals are not lost at various stages of the process, they would become higher-valued products at a very minimal incremental cost. In reviewing this estimation procedure, an error in the mathematics was found and corrected. Therefore, the recovered product value was revised to \$300 per Mg.

5.8 REFERENCES

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8. Reference 3, pp. IV-3, 8, 9.

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14. Peters, M.S. and K.D. Timmerhaus. Plant Design and Economics for Chemical Engineers, Second Edition. New York, McGraw-Hill Book Company, 1968.

15. Reference 13.

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17. Memo from Hustvedt, K.C., EPA:CPB, to files. July 15, 1980. 1p. Summary of Hydroscience survey data.

18. Reference 3, pp. IV-8, 9.

19. Reference 1.

20. U.S. Environmental Protection Agency. Control of Volatile Organic Compound Leaks from Petroleum Refinery Equipment. Research Triangle Park, N.C. Publication No. EPA-450/2-78-036. June 1978. pp.4-45.

21. Reference 3, p. IV-3.

22. Reference 3, pp. IV-9, 10.

23. Letter and attachments from Amey, G.C., Century Systems Corporation, to Serne, J., Pacific Environmental Services. October 17, 1979. 3p. Cost data for VOC monitoring instrument.

24. Reference 3, p. IV-9.

25. Letter from Smith, V.H., Research Triangle Institute, to Honerkemp, R., Radian Corporation. November 30, 1979. 1p. Information about baseline projections.

APPENDIX A

METHODOLOGY FOR ECONOMIC ANALYSIS

Appendix A presents information used in responding to public comments relating to the potential impact of fugitive emission standards for the synthetic organic chemicals manufacturing industry (SOCMI). Section A.1 describes the weighting procedures used to estimate historical production, quantity of sales, and value of sales data. The weights are based on a 1978 International Trade Commission Report. The prices of SOCMI Chemicals during 1978 and the computation of the average price of SOCMI Chemicals are also explained in Section A.1. The methodology used to project SOCMI replacement investment is described in Section A.2. In section A.3, the process used to estimate the cost of capital is described. Section A.4 explains the methodologies and assumptions used to estimate the price and rate of return impacts. Section A.5 lists the references.

A.1 ESTIMATION OF SOCMI PRODUCTION, SALES, AND PRICE VALUES

SOCMI chemicals may be used as primary feedstocks, chemical intermediates, or end use chemicals. Primary feedstocks are produced from crude raw materials and used in the manufacture of other chemicals. Chemical intermediates are products of primary feedstocks and are also used to produce other chemicals. End use chemicals are products of chemical intermediates and/or primary feedstocks and are used either as final goods or as inputs to production processes outside the chemical industry. Data on production, quantity of sales, and value of sales for the synthetic organic chemicals are reported annually by the United States International Trade Commission (formerly known as the United States Tariff Commission) in the report, Synthetic Organic Chemicals: U.S. Production and Sales. Data on production, quantity of sales, and value of sales of the SOCMI chemicals for which data are available are reproduced in Table A-1 from the ITC report for the year 1978.

Reasons for the nonavailability of data on production, quantity of sales, and value of sales for SOCMI chemicals not listed in Table A-1 are outlined in the Introductory Section, pages 1 and 2, of the ITC report.

TABLE A-1. U.S. PRODUCTION AND SALES OF SYNTHETIC[a] ORGANIC CHEMICALS, 1978

Chemicals	Production (1,000 lb)	Sales			
				Price	
		Quantity (1,000 lb)	$1,000	$ per lb	$ per Mg
I. Primary Products from Petroleum and Natural Gas for Chemical Conversion					
Benzene[b] (1° and 2°)	10,503,883	5,144,345	518,323	0.101	220
Cumene	3,380,322	1,579,161	174,249	.110	240
Cyclohexane	2,331,665	2,194,849	245,860	.112	250
Ethylbenzene	8,385,482	365,102	38,616	.106	230
Naphthalene, all grades	156,801	84,642	13,234	.156	340
Styrene	7,186,193	2,882,387	500,786	.174	380
Toluene[b]	7,542,434	4,948,978	377,409	.076	170
Xylenes,[b] mixed	6,412,745	3,375,066	249,435	.074	160
o-Xylene	1,013,131	939,180	103,775	.110	240
p-Xylene	3,515,869	2,178,563	269,139	.124	270
All other aromatics and naphthenes	4,123,482	3,526,357	163,977	.047	100
Acetylene	245,670	...	...	...	...
Ethylene	25,954,627	8,784,177	1,095,624	.125	280
Propylene	13,013,529	5,679,958	526,528	.093	210
Butadiene and butylene fractions	482,789	261,011	50,984	.195	430
1,3-Butadiene, grade for rubber (elastomers)	3,515,206	2,505,025	486,944	.194	430
1-Butene	91,655	75,867	13,793	.182	410
Isobutylene, 2-butene and mixed butylenes	909,301	597,712	65,925	.110	240
Isoprene (2-Methyl-1, 3-butadiene)	184,117	116,969	18,195	.156	340

(continued)

TABLE A-1. (Continued)

Chemicals	Production (1,000 lb)	Sales			
				Price	
		Quantity (1,000 lb)	$1,000	$ per lb	$ per Mg
Dodecene (Tetrapropylene)	359,705	97,144	12,018	.124	270
Nonene (Tripropylene)	431,525	283,539	30,805	.109	240
Subtotal	99,740,131	45,620,032	4,955,619	.109	240
II. Cyclic Intermediates					
Aniline (Aniline oil)	605,772	187,767	41,865	.220	490
Benzoic acid, tech	85,175	36,822	8,686	.240	530
Biphenyl	63,527	17,450	4,224	.24	530
Cresols, total	96,869	94,932	47,630	.50	1,100
Cresylic acid, refined	45,003	46,078	12,991	.28	620
Cyclohexanone	1,161,712	36,992	12,226	.33	730
o-Dichlorobenzene	41,140	44,028	11,810	.27	600
p-Dichlorobenzene	41,224	38,062	10,311	.27	600
α-Methylstyrene	75,571	61,176	10,780	.18	400
Nitrobenzene	575,523	20,192	4,302	.21	460
Nonylphenol	125,167	49,294	11,177	.23	510
Phenol, total	2,681,603	1,431,536	231,622	.16	350
Salicylic acid, tech	47,149	6,335	5,418	.86	1,900
Terephthalic acid, dimethyl ester	5,954,216	...	...	...	...
Toluene-2,4-diamine (4-m-Tolylenediamine)	139,250	...	...	...	...
Subtotal	11,738,901	2,070,664	413,042	0.200	440
III. Miscellaneous Cyclic and Acylic Chemicals					
Benzyl alcohol	8,572	5,642	5,400	.96	210
Caprolactam	918,660	...	...	...	...
p-Hydroxybenzoic acid, methyl ester	...	848	2,320	2.74	6,040

(continued)

TABLE A-1. (Continued)

Chemicals	Production (1,000 lb)	Sales			
		Quantity (1,000 lb)	$1,000	Price	
				$ per lb	$ per lb
Maleic anhydride	341,127	271,469	66,405	.24	530
Butylamines, total	55,804	51,442	26,927	.52	1,150
n-Butylamine, mono-	4,097	4,103	2,318	.57	1,260
Di-n-butylamine	4,921	4,009	2,466	.62	1,370
All other butylamines	46,768	43,330	22,143	.51	1,120
Dimethylamine sulfate	5,904	...	...	...	...
Ethylamines, total	65,623	48,021	24,488	.51	1,120
Diethylamine	15,169	5,712	3,458	.61	1,340
Monoethylamine	36,151	31,950	13,244	.41	900
Triethylamine	14,303	10,359	7,786	.75	1,650
Isopropylamine, mono-	45,844	41,886	14,824	.35	770
Ethanolamines, total	362,027	320,236	109,401	.34	750
Acetonitrile	44,942	...	...	...	...
Acrylonitrile	1,752,302	586,816	134,965	.23	510
Acetic acid, 100%	2,775,520	823,274	120,263	.15	330
Acetic anhydride, 100%	...	132,078	32,032	.24	530
Acrylic acid	325,318	46,503	15,058	.32	710
Adipic acid	1,621,219	...	...	...	...
Fumaric acid	27,993	24,402	9,941	.41	900
Propionic acid	83,078	62,848	10,879	.17	370
Butyraldehyde	782,653	68,168	11,962	.18	400
Formaldehyde (37% by weight)	6,380,959	2,241,958	105,917	.05	110
Acetone:					
From cumene	2,051,811	1,083,662	145,869	.13	290
From isopropyl alcohol	467,602	456,699	71,366	.16	350
2-Butanone (Methyl ethyl ketone)	660,835	669,341	127,007	.19	420
4-Methyl-2-pentanone (Methyl isobutyl ketone)	232,691	155,944	42,703	.27	600
4-Methyl-3-penten-2-one (Mesityl oxide)	33,143	15,797	4,991	.32	710
All other	312,586	101,384	35,560	.35	770
n-Butyl alcohol (n-Propylcarbinol)	755,855	395,494	66,985	.17	370

(continued)

TABLE A-1. (Continued)

		Sales			
				Price	
Chemicals	Production (1,000 lb)	Quantity (1,000 lb)	$1,000	$ per lb	$ per Mg
Methanol, synthetic	6,443,242	3,080,747	181,027	.06	130
n-Butyl acetate, unmixed	122,106	128,161	32,790	.26	570
Ethyl acetate (85%)	181,944	177,973	33,744	.19	420
Ethyl acrylate	299,306	147,541	44,295	.30	660
Isobutyl acetate	...	48,433	12,409	.26	570
Vinyl acetate	1,691,969	942,659	167,107	.18	400
All other	1,504,442	718,456	287,853	.40	880
Ethylene glycol	3,903,889	3,137,188	546,690	.17	370
Glycerol, synthetic only	133,907	116,612	54,448	.47	1,040
2-Methoxyethanol (Ethylene glycol monomethyl ether)	114,381	106,400	29,869	.28	620
2-(2-Methoxyethoxy) ethanol (Diethylene glycol monomethyl ether)	17,066	12,567	3,816	.30	660
Polyethylene glycol	89,849	84,603	31,074	.37	820
Polypropylene glycol	26,829	20,871	7,799	.37	820
Triethylene glycol	119,944	83,901	26,110	.31	680
Carbon tetrachloride	737,030	363,406	41,698	.11	240
Chloroethane (Ethyl chloride)	539,793	159,079	23,428	.15	330
Chloroform	349,169	302,114	53,423	.18	400
Chloromethane (Methyl chloride)	453,810	200,797	28,977	.14	310
1,2-Dichloroethane (Ethylene dichloride)	11,000,619	1,033,313	82,645	.08	180
Dichloromethane (Methylene chloride)	570,098	490,678	114,342	.23	510
1,2,-Dichloropropane (Propylene dichloride)	74,112	33,382	2,120	.06	130

(continued)

TABLE A-1. (Continued)

		Sales			
				Price	
Chemicals	Production (1,000 lb)	Quantity (1,000 lb)	$1,000	$ per lb	$ per Mg
Tetrachloroethylene (Perchloroethylene)	725,457	549,111	53,589	.10	220
1,1,1-Trichloroethane (Methyl chloroform)	644,475	631,243	135,388	.21	460
Trichloroethylene	298,986	298,557	46,588	.16	350
Vinyl chloride, monomer (Chloroethylene)	6,941,123	4,885,688	618,407	.13	290
All other chlorinated hydrocarbons	1,208,509	94,649	31,756	.34	750
Chlorodifluoromethane (F-22)	205,612	139,797	106,236	.76	1,670
Dichlorodifluoromethane (F-12)	327,097	316,864	134,743	.43	950
Trichlorofluoromethane (F-11)	193,735	166,898	57,341	.34	750
Carbon disulfide	476,175	375,962	31,645	.08	180
Epoxides, ethers, and acetals, total	7,584,748	1,658,547	400,521	.24	530
Ethylene oxide	5,012,419	525,113	123,079	.23	510
Ethyl ether, absolute	12,098	...	...	...	...
Propylene oxide	2,046,843	...	...	...	...
All other epoxides, ethers, and acetals	513,388	1,133,434	277,442	.24	530
Phosgene (Carbonyl chloride)	1,296,941	...	...	...	...
Subtotal	75,973,179	29,768,656	5,007,662	0.168	370
Grand Total	187,452,211	77,459,352	10,376,323	0.134	295

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[a] Data presented here are reproduced from Table 1 of Synthetic Organic Chemicals, U.S. Production and Sales, 1978, United States International Trade Commission, Washington, DC 20436.

[b] Production and sales of benzene, toluene, and xylenes by coke-oven operators represent less than 2 percent of total benzene, toluene, and xylenes production and sales and are not included in the table.

First, the ITC reports data for only those chemicals produced by more than three producers; second, producers report data for only those chemicals for which the volume of production exceeds 1,000 pounds or the value of sales exceeds $1,000; and third, many chemicals are manufactured by the industry as intermediate products to produce other chemicals and are never sold in the market.

For the year 1978, the totals of production, quantity of sales, and value of sales of SOCMI chemicals listed in Table A-1 are 85 million Mg, 35 million Mg, and $10 billion, respectively. The average price of SOCMI chemicals for the year 1978 is computed as about $300/Mg (total value of sales/total quantity of sales). The average price of primary SOCMI products from petroleum and natural gas for the year 1978 is $240 per Mg, which is smaller than the average prices of "cyclic intermediates" ($440 per Mg) and "miscellaneous cyclic and acyclic" ($370 per Mg) SOCMI chemicals. Prices of individual chemicals such as benzene, ethylene, propylene, phenol, formaldehyde, and vinyl chloride are $220, $280, $210, $390, $110, and $290 per Mg, respectively. The prices of individual SOCMI chemicals during 1978 ranged between $100 and $6,040 per Mg.

The average price of all chemicals listed in the ITC report under the three major categories "Primary Products from Petroleum and Natural Gas," "Cyclic Intermediates," and "Miscellaneous Cyclic and Acyclic" is computed as $350 per Mg. SOCMI chemicals listed in Table A-1 represent more than 70 percent of the production of all chemicals listed in the ITC report.

To derive appropriate estimates of the historical data (1968-1977), production, quantity of sales, and value of sales in 1978 were computed for all the SOCMI chemicals included in each of the three categories. The computed sums of production, quantity of sales, and value of sales of SOCMI chemicals were divided, respectively, by the corresponding totals for all chemicals listed in the ITC report to get fixed weights for the three categories. These fixed weights were used to compute estimates of production, quantity of sales, and value of sales of chemicals in each category over the period 1975-1978. For example, for 1975, the production of SOCMI chemicals was estimated by a weighted sum of 1975 production data on Primary Products from Petroleum and Natural Gas for Chemical Conversion, Cyclic Intermediates, and Miscellaneous Cyclic and Acyclic Chemicals, as reported in the 1975 ITC report. Table A-2 presents the estimated ratios used to weight the ITC data.

Prior to 1975, the chemicals included in the category Miscellaneous Cyclic and Acyclic Chemicals were reported as Miscellaneous Synthetic Organic Chemicals. A weighting scheme based on 1974 data for this category was developed using the procedure described above and was used to estimate production and sales of SOCMI chemicals in this category for the period 1968-1974. Data on production and sales of SOCMI for the remaining two categories for the period 1968-1974 were estimated using the 1978 weights.

A.2 REPLACEMENT INVESTMENT PROJECTIONS

The projections are based on two key theoretical assumptions: (I) the historical growth rate of capacity, ρ, has been constant over time; and (II) model units have a fixed life of L years. These assumptions are summarized in the following equations:

$$K_T = (1+\rho)^L K_{T-L} \tag{1}$$

$$I_T = \rho K_T + R_T \tag{2}$$

$$R_T = I_{T-L} \tag{3}$$

where

K = industry capacity,
I = gross investment,
R = replacement investment,
T = time subscript,

and K, I and R are measured in terms of model units.

Equation (1) is an algebraic restatement of assumption I. Equation (2) is simply a mathematical definition of gross investment, that is, gross investment, I_T, is equal to additions to new capacity, ρK_T, plus replacement investment, R_T. Equation (3) is an algebraic restatement of assumption II.

TABLE A-2. WEIGHTS USED TO ESTIMATE HISTORICAL PRODUCTION, SALES AND PRICES OF SYNTHETIC ORGANIC CHEMICALS[a]

	Production (Mg)	Quantity of Sales (Mg)	Value of Sales ($ 1,000)	Price[b] ($/Mg)
Primary Products from Petroleum and Natural Gas				
Total SOCMI Chemicals[c]	45,241,826	20,693,111	4,955,619	240
ITC Grand Total[d]	58,489,843	29,157,773	6,159,507	210
Weight[e]	77%	71%	80%	-
Cyclic Intermediates				
Total SOCMI Chemicals[c]	5,324,731	939,249	413,042	440
ITC Grand Total[d]	9,042,805	4,015,536	2,803,327	700
Weight[e]	59%	23%	15%	-
Miscellaneous Cyclic and Acyclic Chemicals				
Total SOCMI Chemicals[c]	34,461,208	13,502,974	5,007,612	370
ITC Grand Total[d]	41,776,760	17,660,815	8,581,663	490
Weight[e]	82%	77%	58%	-
Miscellaneous Chemicals 1974 Figures				
Total SOCMI Chemicals[c]	33,416,656	15,793,169	3,607,825	230
ITC Grand Total[d]	45,633,845	21,514,545	7,815,487	360
Weight[e]	73%	73%	46%	-

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[a] 1978 figures except where indicated.

[b] Price is computed by dividing the value of sales by the quantity of sales.

[c] Total SOCMI chemicals consist of all the SOCMI chemicals listed in Table A-1.

[d] ITC Grand Total includes SOCMI chemicals and other chemicals listed in Table 1 of the respective categories in the ITC reports.

[e] Weight is computed as the ratio of total SOCMI chemicals to ITC grand total.

Source: Synthetic Organic Chemicals: U.S. Production and Sales, 1978, 1974, United States International Trade Commission, Washington, DC 20436.

Appropriately lagging Equation (2) and back substituting from (2) into (3), it can be shown that

$$R_T = \rho \sum_{i=1}^{\infty} K_{T-iL} \tag{4}$$

Further, by substituting for the various K_{T-iL} in Equation (4) using Equation (1), and rearranging terms, the following result is obtained:

$$R_T = K_{T-L} \sum_{i=0}^{\infty} \frac{\rho}{(1+\rho)^{iL}} \tag{5}$$

The expression $\sum_{i=0}^{\infty} \frac{\rho}{(1+\rho)^{iL}}$ is a constant and, if ρ is assumed to be 0.06 and L to be 20, approximately equal to 0.087. Equation (5) can be used to project replacement investment in any year, T, if an estimate of the capital stock in the (T-L)th year is available. For SOCMI, capital stock data are available for 1976. This information, together with an assumed historical growth rate of 6 percent, was used to estimate the capital stock for the years 1961 to 1965 by means of Equation (1). The resulting capital stock estimates are then used in Equation (5) to project replacement investment in SOCMI for each of the five years following proposal of any regulatory alternatives (1981-1985), on the basis of the empirical assumption that each model unit has a life of 20 years. The annual projections of replacement investment are then summed to obtain a projection of the number of replacement facilities subject to the provisions of any regulatory alternative in the fifth year following its proposal. The projections of replacement investment obtained by applying this methodology are presented in Table A-3.

TABLE A-3. PROJECTIONS OF REPLACEMENT INVESTMENT

	Number of replacement capacity units	
Year	Annual	Cumulative
1981	49	49
1982	51	100
1983	55	155
1984	58	213
1985	61	274

A.3 METHODOLOGY FOR COMPUTING COST OF CAPITAL TO SYNTHETIC ORGANIC CHEMICAL MANUFACTURERS

The cost of capital for any new project is the cost of equity, debt, and preferred stock, weighted by the percentage of funds generated by each type of financing, that is,

$$k_c = k_e \frac{E}{I} + k_i \frac{D}{I} + k_p \frac{P}{I} \qquad (1)$$

where

k_c ≡ cost of capital

k_e ≡ cost of equity capital

k_i ≡ cost of debt capital

k_p ≡ cost of preferred stock capital

E ≡ the amount of equity used to finance a given investment

D ≡ the amount of debt used to finance a given investment

P ≡ the amount of preferred stock used to finance a given investment

I ≡ the total funds needed for the investment

The k variables are interest rates representing the aftertax return on investment that is needed to pay stock dividends and interest on debt. Each k term is a nominal interest rate in that it contains an implicit allowance for inflation. However, the cost of capital computed with equation (1) is treated in the text as the real dollar interest rate that would prevail in times of economic stability. The nominal rate is used as though it were a real rate partly to ensure that estimates of the cost and other adverse economic effects of investment in air pollution controls will be biased upward rather than downward, and partly to avoid miscalculations that could result from using the wrong inflation rate to convert the nominal rate to a real rate.

The first step in estimating Equation (1) is to determine the relevant weights for the three types of financing. It is assumed that the proportion of debt, equity, and preferred stock to be used on any new project will be the same as currently exists in the firm's capital structure. This implies that the firm is currently using the optimal mix of financing. Figures for the three types of funds came from the COMPUSTAT tapes, supplied by Standard & Poor's Corporation, for each firm's fiscal year ending in 1977. Common equity included the par value of common stock, retained earnings, capital surplus, self-insurance reserves, and capital premium, while debt included all obligations due more than a year from the company's balance sheet date. Preferred stock represented the net number of preferred shares outstanding at year-end multiplied by the involuntary liquidating value per share.

The next step in calculating Equation (1) is to estimate the cost of equity financing. Two approaches are commonly used: the results derived from the capital-asset pricing model (CAPM) and the results derived from the dividend capitalization model (DCM). The CAPM examines the necessary returns on a firm's stock in relation to a portfolio comprised of all existing stocks, while the DCM evaluates the stream of dividends and the discount rate needed to arrive at the firm's existing share price. The required return on equity using the CAPM is:

$$k_e = i + \beta\,(k_m - i) \qquad (2)$$

where

$i \equiv$ the expected risk free interest rate
$k_m - i \equiv$ the expected excess return on the market, and
$\beta \equiv$ the firm's beta coefficient.

The beta coefficient is an historical measure of the extent to which a firm's stock price fluctuates in relation to an index of the stock market as a whole. β takes on a value of zero for a stock whose price is constant, a value of one for a stock whose price follows the same path as an index of the whole stock market, and a value of greater than (less than) one for a stock whose price fluctuates more (less) dramatically than does the general index. The CAPM is thus a modified regression equation in which β is the slope of a straight line relating k_e and k_m.
The required return on equity using the DCM is:

$$k_e = \frac{D_1}{P_o} + g \qquad (3)$$

where

$D_1 \equiv$ the dividend expected in period 1
$P_o \equiv$ the share price at the beginning of period 1
$g \equiv$ the expected rate of dividend growth, assumed to be constant.

The DCM is developed on the assumptions that (1) the price of a stock is the present value of anticipated dividends, and that (2) these dividends grow each year by a fixed percentage that is less than the required return on equity.

Figures for Equation (2) were developed in the following manner. The expected risk-free rate was assumed equal to the yield on a 3-month Treasury Bill, as reported in the October 1, 1979, Wall Street Journal. The current yield was 10.46 percent. This corresponds to the yield from a bond with no possibility of default and offering no chance of a capital loss and is therefore riskless. The firm's beta coefficients came from the September 24, 1979, Value Line Investment Survey. The expected excess return equalled 2.9646 percent, the 5-year average (July 1974-June 1979) of the monthly excess returns on the Standard & Poor's 500 Stock Index multiplied by twelve.

Figures for Equation (3) came from two sources. Both share price and expected yearly dividends came from figures reported in the October 1, 1979, Wall Street Journal. The growth rate was calculated from data contained on the COMPUSTAT tapes. Note that the use of historical data does not necessarily make the estimated rate of return on capital inconsistent with the fourth quarter 1978 cost data used in this study as both short- and long-term interest rates are currently in a state of flux. Three different growth rates were tried: the 5-year average growth of total assets, the 5-year average growth of per share earnings, and the 5-year average growth of dividends.

A number of theoretical reasons exist for preferring the CAPM approach to the DCM for estimating the required return on equity, but the figures calculated revealed a more practical justification. Using growth estimated from per share earnings or dividends resulted in a number of firms having negative required returns with the DCM method. Although using the growth in assets resulted in only one firm with a negative required return, several firms had extremely low returns (less than 10 percent). It is unreasonable to expect that stockholders would demand a return on their stock that is less than the existing yield on Treasury Bills, yet all three variants of the DCM method led to this conclusion for a number of firms. From these considerations it was decided to use the CAPM calculations as the required return on equity.

The third step in estimating Equation (1) is calculating the cost of debt financing. This would be a relatively easy estimation if interest rates did not change over time. Past yields on old issues of bonds would suffice. Since interest rates have been increasing, it was felt that a more forward-looking rate was required. The method selected was to take the average yield as given in the September 3, 1979, Moody's Bond Survey for the firm's bond ratings class as the necessary yield the firm must offer on long-term debt. The firm's ratings class came from the September 1979 Moody's Bond Record or the 1979 Moody's Industrial Manual. A small number of firms were not rated by Moody's. One firm was ranked in Standard and Poor's Bond Guide and this was used to approximate a Moody's bond class. For other firms, data concerning bank notes, revolving credit, or term-loan agreements that tied the interest rate on these types of debt to the current prime rate were obtained from 1979 Moody's Industrial Manual or the Standard and Poor's Corporation Records. This data were taken to measure the necessary yield on long-term debt for such firms. Table A-4 presents

TABLE A-4. YIELDS BY RATING CLASS FOR COST OF DEPT FUNDS, 1979
(prime rate = 13.50 %)

Ratings Class	Yield (percent)
AAA	9.25
AA	9.59
A	9.72
BAA	10.38
BA	11.97
B	12.395

the yields by ratings class and the prime rate (as of September 1, 1979) used for the cost of debt funds.

The yield on long-term debt does not represent the aftertax cost of debt financing since interest charges are tax deductable. To arrive at the aftertax cost of debt capital, the yield must be multiplied by 1 minus the marginal tax rate.

$$k_i = k(1 - t)$$

where

$k \equiv$ the yield on bonds, and
$t \equiv$ the marginal tax rate.

It is assumed that the firms in the sample are profitable, so that taxes must be paid, and that their marginal tax rate is 48 percent.

The last step in estimating Equation (1) is to arrive at the cost of preferred stock financing. Unlike debt, preferred stock does not have a maturity date, so that the current yield should approximate the yield on new issues. The yield is:

$$k_p = \frac{D}{P}$$

where

$D =$ stated annual dividend, and
$P =$ the price of a share of preferred stock.*

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*Note that as preferred stock dividends do not increase over time the growth factor required in the discounted cash flow model (equation 3) is omitted here.

The figures for dividends and share price came from the October 1, 1979, Wall Street Journal or, if not included in this source, from the January 1, 1979, listing in the Daily Stock Price Record. A number of firms did not have their preferred stock listed in either source, yet had preferred stock in their capital structures. All used less than 15 percent preferred stock, with the majority less than 5 percent. For these firms the aftertax yield on preferred stock was set equal to the pretax yield on long-term debt.

Table A-5 lists the cost of capital for all 100 firms in the sample, and also includes some of the components of equation (1). These firms represent the best available sample of the approximately 600 firms in the industry. However, it is likely that on the average the firms included in the sample are larger than the firms excluded, as many small firms do not have to publish detailed financial records. This potential sample bias may have resulted in a slight underestimate of the industry's cost of capital because larger firms are often able to acquire investment funds more cheaply than smaller firms. This is because larger firms are usually able to reduce their transactions costs of borrowing and because they represent a less risky investment due to product diversification than small firms.

A.4 METHODOLOGICAL CONSIDERATIONS: PRICE AND RATE OF RETURN IMPACTS

Let P denote product price, Q denote unit output, TOC denote total operating costs, K denote the amount of capital invested in the unit, r denote the rate of return on capital and t denote the tax rate in a given year. The aftertax rate of return on capital invested in the unit may then be defined as:

$$r = \frac{(1-t)\ (PQ - TOC)}{K} \qquad (1)$$

where (PQ - TOC) is the unit's pretax net revenues from its operations in that year. Now, assume that the unit is required to change its operating costs and level of capital investment in order to comply with the implementation of some regulatory alternative. Under the full cost absorption scenarios the unit will be unable to adjust the the price of its product or

TABLE A-5. FINANCIAL DATA FOR 100 CHEMICAL FIRMS[1-11]

Name	Cost of capital	Return on equity	Return on debt[a]	Return on preferred stock[b]	Proportion of equity	Proportion of debt	Proportion of preferred stock
Abbott Labs	12.014	14.018	9.590	--	.77262	.216575	.010804
Akzona	10.276	13.276	10.380	--	.61914	.380859	.000
Alco Standard Corp.	12.151	13.425	15.120	--	.64134	.259343	.099317
Allied Chem Corp.	10.091	13.721	9.720	--	.58118	.418825	.000
American Cyanamid	11.083	13.425	9.590	--	.72252	.277480	.000
Armco Steel Corp.	10.588	13.276	9.720	6.461	.66880	.306858	.024337
Atlantic Richfield	9.749	13.128	9.590	--	.51602	.362174	.121802
Beatrice Foods	11.232	12.832	9.250	7.429	.79803	.194329	.007644
Bendix Corp.	11.118	13.425	9.720	3.333	.72911	.248140	.022754
Bethlehem Steel Corp.	10.913	14.018	9.720	--	.65360	.346402	.000
Borden, Inc.	10.484	12.683	9.590	--	.71317	.285155	.001677
Borg-Warner Chem.	11.863	13.128	9.720	--	.82756	.145263	.027181
Brown Co.	9.813	12.387	12.395	--	.56680	.433202	.000
CPC International Inc.	11.638	13.128	9.590	--	.81691	.183087	.000
Celanese Corp.	10.181	13.128	11.970	10.084	.53511	.396896	.067997
Charter International Oil	9.175	14.166	12.395	--	.27557	.623167	.101265
Cities Service Co.	10.395	12.980	9.720	--	.67388	.326120	.000
Combustion Engineering	11.494	14.314	9.720	--	.68700	.296229	.016774
Continental Oil	10.881	13.721	9.590	2.564	.67568	.321308	.003009
Crompton & Knowles	11.298	13.425	14.450	--	.53329	.375634	.091078
Dart Indust.	10.689	14.166	9.720	4.211	.63113	.231645	.137221
Dayco Corp.	8.270	12.980	11.970	6.071	.30351	.666445	.030044
De Soto, Inc.	11.499	13.128	13.750	--	.72746	.272535	.000
Diamond Shamrock Corp.	9.790	13.721	9.720	--	.54639	.453615	.000
Dow Chemical	10.060	14.018	9.590	--	.56176	.438236	.000
Du Pont De Nemours	11.328	13.573	9.250	8.654	.72512	.232172	.042712
Eastern Gas & Fuel Associates	11.605	14.018	14.180	--	.63681	.363188	.000
Essex Chem. Corp.	12.502	14.166	12.395	--	.78453	.215465	.000

TABLE A-5. (Continued)

Name	Cost of capital	Return on equity	Return on debt[a]	Return on preferred stock[b]	Proportion of equity	Proportion of debt	Proportion of preferred stock
Exxon Corp.	11.875	13.276	9.250	--	.83450	.165504	.000
FMC Corp.	10.183	13.573	9.720	6.250	.59257	.339730	.067701
Ferro Corp.	12.369	13.276	9.720	--	.88968	.110317	.000
Firestone Tire & Rubber	10.610	12.980	9.720	--	.70096	.299038	.000
Ford Motor Co.	12.069	13.276	9.250	--	.85743	.142565	.000
GAF Corp.	9.398	13.573	10.380	7.559	.44490	.387035	.168061
General Electric Co.	12.130	13.721	9.250	--	.82148	.178521	.000
General Motors Corp.	12.798	13.425	9.250	8.715	.91962	.063516	.016862
General Tire & Rubber	11.440	13.276	11.970	--	.73287	.258968	.008163
Georgia-Pacific Corp.	10.793	13.573	9.590	--	.67625	.323751	.000
Goodrich (B.F.) Co.	10.430	13.276	10.380	8.864	.62957	.349707	.020723
Goodyear Tire & Rubber Co.	10.101	12.980	9.720	--	.63679	.363210	.000
Gulf Oil Corp.	11.745	12.980	9.250	--	.84880	.151203	.000
Hercules, Inc.	11.177	13.869	9.720	--	.69461	.305394	.000
Inland Steel	10.092	12.980	9.590	--	.62702	.352735	.020249
Insilco Corp.	9.339	13.276	11.970	7.752	.41885	.475634	.105511
Interlake, Inc.	11.331	13.128	9.720	--	.77736	.222640	.000
International Harvester	10.534	13.573	9.720	--	.63297	.348230	.018796
Kaiser Steel Corp.	11.688	14.018	14.000	--	.63274	.345717	.021539
Kraft, Inc.	10.774	12.683	9.250	--	.75752	.242479	.000
Marathon Oil Co.	9.582	13.128	9.720	--	.56074	.439257	.000
Martin Marietta Chem.	11.238	13.276	9.720	--	.75212	.247882	.000
Mead Corp.	10.000	13.869	9.720	4.308	.56423	.398718	.037048
Merck & Co.	12.309	13.573	9.250	--	.85481	.143358	.001827
Minnesota Mining & Manuf.	12.572	13.869	9.250	--	.85677	.143235	.000
Mobil Oil Corp.	10.868	13.128	9.250	--	.72833	.271665	.000
Monsanto Co.	10.970	13.573	9.590	5.000	.69690	.300335	.002767
Morton-Norwich Products	10.726	13.721	9.720	--	.65441	.345589	.000

TABLE A-5. (Continued)

Name	Cost of capital	Return on equity	Return on debt[a]	Return on preferred stock[b]	Proportion of equity	Proportion of debt	Proportion of preferred stock
National Distillers & Chem.	11.037	13.128	9.720	9.193	.73310	.251565	.015334
National Steel Corp.	9.909	12.683	9.590	--	.63946	.360538	.000
Northwest Indust.	8.015	13.869	10.380	2.9412	.32561	.617085	.057301
Owens-Corning Fiberglass	11.653	13.425	9.720	--	.78828	.211721	.000
PPG Industries	10.596	13.276	9.590	--	.67661	.323394	.000
Penwalt Corp.	9.013	13.276	9.720	7.529	.41712	.369200	.213675
Pfizer	11.244	14.018	9.590	--	.69289	.307113	.000
Phillips Petroleum Co.	11.670	13.721	9.250	--	.76982	.230179	.000
Procter & Gamble Co.	11.824	13.276	9.250	--	.82842	.171428	.000153
Quaker Oats Co.	10.946	13.573	9.720	9.008	.651578	.262094	.086328
Reeves Bros. Inc.	10.629	12.535	10.380	--	.732870	.267130	.000
Reichold Chems.	10.647	13.425	10.380	--	.571986	.295871	.132143
Republic Steel Corp.	11.305	13.425	9.720	--	.746819	.253181	.000
Riegel Textile Corp.	11.201	12.980	11.970	--	.736598	.263402	.000
Rockwell International	9.589	12.535	9.720	5.398	.602132	.309032	.088836
Rohn and Haas Co.	10.739	13.721	9.720	--	.655939	.344061	.000
SCM Corp.	10.835	14.018	10.380	--	.630766	.369234	.000
Scott Paper Co.	10.784	13.721	9.590	--	.660791	.333680	.005529
Shakespeare Co.	11.229	13.276	14.000	--	.658505	.341495	.000
Sherwin-Williams Co.	9.617	12.980	10.380	10.00	.523981	.422439	.053579
Squibb Corp.	11.266	14.018	9.590	--	.695345	.304655	.000
A. E. Staley Mfg. Co.	10.428	13.573	9.720	--	.629947	.368508	.001544
Stauffer Chemical Co.	10.188	13.425	9.720	--	.613351	.386649	.000
Sterling Drug	12.595	13.276	9.590	--	.917816	.082184	.000
Sun Chem. Corp.	10.427	13.573	12.395	--	.558689	.441311	.000
Sybron Corp.	10.786	13.869	9.720	--	.616191	.319517	.064292
Tenneco, Inc.	9.155	12.980	10.380	3.887	.505890	.442129	.051981
Texaco	11.230	12.980	9.250	--	.785863	.214137	.000
Texfi Indust.	10.090	13.275	16.000	--	.356904	.643096	.000
Textron Inc.	10.085	13.425	9.720	6.222	.577353	.252757	.169890
Union Camp Corp.	11.359	13.276	9.590	--	.768639	.231361	.000
Union Carbide Corp.	10.775	13.573	9.590	--	.674170	.325830	.000

TABLE A-5. (Continued)

Name	Cost of capital	Return on equity	Return on debt[a]	Return on preferred stock[b]	Proportion of equity	Proportion of debt	Proportion of preferred stock
Union Oil, Calif.	10.577	13.128	9.590	--	.663994	.295934	.040072
Uniroyal	10.514	13.425	11.970	16.000	.521603	.423786	.054611
U.S. Gypsum	10.726	13.276	9.590	5.539	.686341	.223477	.090182
U.S. Steel Corp.	10.919	13.573	9.590	--	.690912	.309088	.000
Upjohn Co.	11.052	13.573	9.590	--	.706383	.293617	.000
Vulcan Materials Co.	10.675	12.980	9.720	--	.709218	.290782	.000
Walter (Jim) Corp.	9.019	13.721	11.970	4.444	.398726	.491966	.109308
Westinghouse Electric Corp.	12.596	14.018	9.720	8.837	.838775	.155115	.006110
Weyerhaeuser Co.	10.402	14.166	9.590	5.957	.583685	.357341	.058973
Wheeling-Pittsburgh Steel	11.238	13.869	14.000	12.739	.512893	.381136	.105972
Whittaker Corp.	10.070	14.314	11.970	--	.457808	.517470	.024722
Wit Chem. Corp.	10.736	13.573	9.720	3.313	.673790	.292825	.033385

[a] The return on debt data represent pretax estimates and are multiplied by 0.52 to obtain the aftertax rates used in computing the cost of capital.

[b] Dashes indicate missing data. In these cases the pretax returns on debt were used to compute the cost of capital.

unit output. Consequently, the rate of return on investment, r, will change. The formula used to estimate this impact is obtained by totally differentiating Equation (1) with respect to TOC and K; that is,

$$dr = - \frac{(1-t)\ dTOC}{K} + \frac{(1-t)\ (PQ-TOC)\ dK}{K2} \qquad (2)$$

Substituting in (2) from (1) and rearranging terms, it follows that:

$$-dr = \frac{(1-t)\ dTOC + rdK}{K} \qquad (3)$$

Equation (3) is the formula used to calculate the full cost absorption rate of return impacts.

Price impacts are estimated on the basis of the assumption that firms will be able to maintain the preregulation rate of return (r) by increasing product prices. Thus, r is now a constant and P a variable. Rearranging terms in Equation (1), it may be shown that:

$$P = \frac{TOC + r\ K/(1-t)}{Q} \qquad (4)$$

In full cost pass through scenarios, changes in TOC and K leave r and Q unaffected but result in a change in P. The formula for estimating this change in P may be obtained by total differentiating Equation (4) with respect to TOC and K; that is,

$$dP = \frac{dTOC + rdK\ /(1-t)}{Q} \qquad (5)$$

Equation (5) is the formula used to estimate the full cost pass through price impacts.

A.5 REFERENCES

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APPENDIX B

AGGREGATION OF MODEL UNIT IMPACTS

Sections 2, 4, and 5 present data for fugitive emissions on a source-by-source basis. This information can be combined with the data on model units given in Section 3 to estimate impacts on a model unit basis.

For example, in computing the estimated fugitive emissions from model unit B, the emission factors for SOCMI developed in Section 2 are applied to the equipment counts for unit B given in Section 3. The sum of emissions for each source type represents the estimated emissions for the model unit. This procedure is demonstrated in Table B-1 for model unit B. Similarly, emission reductions achieved by various control options computed for each source type and presented in Section 4 can be aggregated to estimate emission reductions achievable on a model unit basis. Table B-2 presents a summary of estimates of emission reductions achievable for the three model units. Cost estimates may be aggregated in the same manner. The capital or annualized costs for any fugitive emission source type in a model unit is determined by applying the per source estimate to the number of sources in the model unit. Examples of this technique are shown in Table B-3 (Capital Costs) and Table B-4 (Annualized Costs).

TABLE B-1. EXAMPLE OF EMISSIONS ESTIMATED FOR MODEL UNIT B IN ABSENCE OF STANDARDS

Emissions Source	Number of Sources	Emission Factor, kg/hr/source	Annual Emissions, Mg/yr[a]
Pump seals			
Light Liquid	29	0.0494	12.55
Heavy Liquid	30	0.0214	5.62
Valves			
Gas	402	0.0056	19.72
Light Liquid	524	0.0070	32.59
Heavy Liquid	524	0.00023	1.06
Safety/relief valves			
Gas	11	0.1040	10.02
Open-ended lines	410	0.0017	0
Compressors	2	0.228	3.99
Sampling connections	26	0.0150	3.42
Flanges	2400	0.00083	17.45
Total			99.51

[a] For estimating purposes, one operating year was assumed to be 8760 hours.

TABLE B-2. ESTIMATE OF EMISSION REDUCTIONS ACHIEVABLE FOR MODEL SOCMI UNITS IN MG/YR

Source	Control Method	Baseline Emissions[a]			Control Efficiency	Controlled Emissions			Emissions Reduction		
		A	B	C		A	B	C	A	B	C
Pumps											
Light Liquid	Leak detection and repair[b]	3.46	12.55	39.38	0.61	1.36	4.92	15.44	2.10	7.63	23.94
Heavy Liquid		1.31	5.62	17.43	---	1.31	5.62	17.43	0	0	0
Valves											
Gas	Leak detection and repair[b]	4.86	19.72	60.44	0.73	1.31	5.32	16.32	3.55	14.40	44.12
Light Liquid		8.15	32.59	100.63	0.59	3.34	13.36	41.26	4.81	19.23	59.37
Heavy Liquid		0.27	1.06	3.26	---	0.27	1.06	3.26	0	0	0
Safety/relief valves	Rupture disk										
Gas		2.73	10.02	30.06	1.0	0	0	0	2.73	10.02	30.06
Open-ended lines[c]	Plugs & Caps	0	0	0	1.0	0	0	0	0	0	0
Flanges	No control	4.36	17.45	53.80	---	4.36	17.45	53.80	0	0	0
Sampling connections	Closed purge systems	0.92	3.42	10.51	1.0	0	0	0	0.92	3.42	10.51
Compressors	Vented seal areas	2.00	3.99	15.98	1.0	0	0	0	2.00	3.99	15.98
Total		28.06	106.42	331.49		11.95	47.73	147.51	16.11	58.69	183.98
%Reduction									57	55	56

[a] Baseline emissions means emissions in the absence of standards.

[b] Monthly monitoring program presented.

[c] As discussed in Section 3 of this document, open-ended lines are assumed to be controlled at baseline.

TABLE B-3. SUMMARY OF AGGREGATED CAPITAL COST ESTIMATES FOR MODEL SOCMI UNITS, 1978$

Emission Source	Control Method	Model Unit A	Model Unit B	Model Unit C
Pump seals, light liquid	Leak detection and repair program	320	1,170	3,590
Valves, gas and light liquid	Leak detection and repair program	470	1,900	5,830
Safety/relief valves, gas[a]	Rupture disks	7,820	28,680	86,050
Compressor seals[b]	Vented seal areas	1,590	3,170	12,690
Sampling connections	Closed purge systems	3,220	11,960	36,800
		8,500[c]	8,500[c]	8,500[c]
		21,910	55,380	153,460

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[a] Assumes a 50/50 split between systems using 3-way valves and systems using block valves.

[b] Assumes a 50/50 split between systems tied to an enclosed combustion device and systems tied to a flare; also assumes 60 percent of the compressors in the industry are already controlled.

[c] Monitoring instrument cost.

TABLE B-4. ANNUALIZED COST ESTIMATES FOR SOCMI MODEL UNITS, 1978$

Emission Source	Control Method	Model Unit A	Model Unit B	Model Unit C
Pump seals, light liquid	Leak detection and repair program[a]			
Annualized capital cost		50	190	590
Annual operating cost		1,890	5,770	21,290
Valves, gas and light liquid	Leak detection and repair program[a]			
Annualized capital cost		80	310	950
Annualized operating cost		2,970	11,970	36,840
Safety/relief valves, gas	Rupture disks			
Annualized capital cost		1,520	5,570	16,700
Annual operating cost		700	2,580	7,750
Compressor seals	Vented seal areas			
Annualized capital cost		260	520	2,060
Annual operating cost		140	280	1,140
Sampling connections	Closed purge systems			
Annualized capital cost		530	1,950	6,000
Annual operating cost		290	1,070	3,280
		1,960[b]	1,960[b]	1,960[b]
		3,040[c]	3,040[c]	3,040[c]
Total annualized costs		13,430	36,210	101,600
Product recovery credit		(4,830)	(17,610)	(55,200)
Net annualized costs		8,600	18,600	46,400

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[a] Monthly monitoring program presented.

[b] Monitoring instrument - annualized capital cost.

[c] Monitoring instrument - annual operating cost.